Tropical Products Institute

G144

Fish handling, preservation and processing in the tropics: Part I

This report was produced by the Tropical Products Institute, a British Government organisation which co-operates with developing countries in helping them to derive greater benefit from their plant and animal resources. It specialises in post-harvest problems and will be pleased to answer requests for information and advice addressed to the Director.

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SUMMARY

Fish handling, preservation and processing in the tropics: Part 1

This report is the first of two TPI Reports, G144 and G145, which together present 52 lectures for an eight-week training course suited to people working at middle management level in both Government and Industry. The lectures should be used in conjunction with audio-visual aids, demonstrations and practical sessions.

In this report, the aims of hygienic handling, preservation and processing of fish in the tropics are discussed. Chilling and freezing, as well as storage and distribution of chilled and frozen products are described in detail. Other subjects covered include carriage of live fish, packaging methods for fishery products, and the instruments used in the fish processing industry.

RÉSUMÉ

Manutention, conservation et transformation due poisson dans les pays tropicaux: 1ère Partie.

Ce rapport est le premier de deux rapports de l'Institut des Produits Tropicaux, G144 et G145, qui rassemblent 52 conférences pour un cours de formation de huit semaines convenant á des personnes occupant un poste administratif moyen dans le Gouvernement et l'Industrie. Ces conférences doivent être complétées par des moyens audio-visuels, des démonstrations et des séances de travaux pratiques.

Dans ce rapport, les buts du maintien des conditions d'hygiéne pour la manutention, la conservation et la transformation du poisson dans les pays tropicaux sont discutés. La réfrigération et la congélation de même que le stockage et la distribution des produits réfrigérés et congelés sont décrits en détail. Les autres sujets traités incluent le transport de poisson vivant, les méthodes d'emballage des produits de la pêche et les outils utilisés dans l'industrie de transformation du poisson.

RESUMEN

Manejo, conservación y elaboración de pescado en las regiones tropicales. 1d Parte.

Este informe es el primero de dos trabajos producidos por el TPI–G144 y G145 – los cuales en conjunto ofrecen 52 conferencias para un curso de adiestramiento de ocho semanas de duración, apropiado para individuos que trabajen a nivel medio de

administración tanto en el gobierno como en la industria. Las conferencias deberán usarse en conjunción con ayudas audividuales, demostraciones y sesiones prácticas.

En este informe se analizan los objetivos del manejo higiénico, la conservación y la elaboración de pescado en las regiones tropicales. La refrigeración y la congelación, así como el almacenaje y la distribución de productos refrigerados y congelados se describen detalladamente. Otros temas tratados incluyen el transporte de pescado vivo, métodos de empaquetado para productos de pesquería, así como los instrumentos usados en la industria de la elaboración del pescado.

Introduction

The set of fifty-two lectures covered by TPI Reports G144 and G145 has been prepared for a course lasting approximately eight weeks. The course is designed for people at middle management level in both Government and Industry. Government staff would include Fisheries Officers and Senior Extension Workers who have a fisheries background and degree level qualifications.

Each lecture session would normally last for about 45 minutes, although some might be expanded to provide two such sessions. Much depends on the linguistic competence of the lecturers and participants and also on the students' level of understanding of basic science. The course should include many practical and demonstration sessions to illustrate the theoretical considerations presented here. In general terms one half of the course time would be devoted to lecture sessions and one half to practice and observation. Extensive use of overhead projector, blackboard, colour transparencies and films is recommended. A list of films suitable for showing during the course is appended.

World fisheries

Most definitions of fishing would include the capture (or culture) of not only fin fish but also the crustacean and molluscan shellfish, whales, seals, turtles, crocodiles and other mammals and reptiles and the algae – any aquatic life in fact. Fishing in this very broad sense is the last remaining hunting activity of man. In almost every other food producing industry the raw material is under the control of the producer long before the harvest. The implications of this factor for the fish technologist are obvious; he must be prepared to deal with a variety of widely different sorts of raw material.

FISH AS FOOD

The aquatic resources are finite and unless man interferes in some way to increase productivity, for example, by culture, habitat improvement, or re-stocking etc., there will come a time when the quantity of fish available to the world's people cannot be increased to meet the needs of the increasing population. The technologist's or processor's task is to make the best possible use of the raw material available, ensuring that the consumer gets the marine products he wants in the form in which he wants them. The processor should thus ideally understand both the science and the technology of the processes he uses so that he can modify these at need. He should also understand the market demand. Such processors, who can modify procedures through a scientific understanding, are usually called technologists; technicians on the other hand carry out routine processes but are not trained to modify or improve these. Now, and in the immediate future, there is a need to upgrade and improve many products so that they keep better, are made more attractive to consumers, or are safer to eat. There is also a need to find ways of using animals not at present commonly eaten and thus to devise new products. Examples include the efforts that are now being made to use the small fish species which comprise the by-catch in the shrimp fisheries, the efforts being made to utilise krill, and the efforts which will have to be made to use the unfamiliar mesopelagic species of fish which are at present seldom caught. A quick look at some simple statistics emphasises several of these points.

Changes in world fish catches and population

Year	World population (millions)	World fish catch (millions of tonnes)	Quantity per caput (kg)
1930	2 000	20	10
1960	3 000	50	60
1970	4 000	70	57
1975	4 000	73	55
2000	*6 267	*114	55

*projected

From this table it would appear at first sight that the quantity of fish available to the individual has increased in a quite remarkable fashion in the last 40 years. A little consideration shows that this is only partially true. For one thing, much of the fish which is being caught and is included in the second column is converted into fish meal which is largely used for animal feeding and thus only becomes available to man at second hand. Nevertheless it *does* become available and without fish meal the immense increase in land animal production which has taken place would not have been possible. However, all the figures in the final column are averages and there is a great deal of difference in the consumption rates in different parts of the world. In the developed countries of North America, Western Europe, Oceania etc., fish consumption rates are generally much higher than those of the less developed countries. Robinson estimated the following per capita consumption rates for 1970 (his figures refer only to the consumption of fish for human food).

	Kg/head
World average	*11.8*
Developed countries	*11.5*
N. America	15.4
W Europe	20.3
Oceania	12.4
Developing countries	*7.4*
Africa	7.1
Latin America	6.5
Near East	2.4
Asia	8.5
Centrally Planned	11.3
Asia	8.1
USSR	23.9
Eastern Europe	8.7

These figures mean almost nothing unless they are related to the intake of other animal protein. On a global basis fish represents about 14 per cent of all the animal protein eaten but, once again, there are wide variations from country to country.

Countries of South America tend to have a high meat consumption compared with that of fish, whereas countries of the Far East and Africa eat greater percentages of fish. In general, the more developed countries of Europe and North America have a much higher intake of animal protein than do people in the developing countries. Animal protein is always expensive. The table below shows how closely consumption of animal protein follows average income, although the South American countries also illustrate the point that low-income producer countries are sometimes able to retain much of their production for home consumption.

Country	Fish as a percentage of animal protein supply 1964–1966	Per caput consumption kg per annum of fish and meat 1970
Argentina	2.5	125.5
Uruguay	1.5	137.5
UK	7.5	98.1
USA	4.8	124.3
Japan	57.8	76.4
Burundi	3.9	8.4
Jamaica	41.5	55.0
Haiti	6.4	9.3
Dominican Republic	26.6	25.7
Indonesia	65.4	14.7

EMPLOYMENT

Fishing industries are also important because they provide employment and income for large numbers of people. It is thought that between 8 and 10 million people are

engaged as fishermen throughout the world and that probably an equal number are employed in industries which serve the primary producers such as fish traders, processors, boat builders, fishing gear manufacturers and others.

A very high proportion of this vast number of people are self-employed and work at the subsistence level. The industrialised countries of the developed world tend to employ relatively small numbers of people who produce large quantities of fish, whereas the small boat subsistence fisheries of the developing world produce small quantities of fish with a large labour force.

For example, the roughly 5 000 Icelandic fishermen produce more than 150 tonnes of fish each every year whereas 23 000 Malawian fishermen produce approximately 3 tonnes of fish each a year. In Indonesia it is estimated that the 880 000 fishermen produce a little over 1.4 tonnes of fish each a year. Similarly, there are great differences in the amount of capital invested per head in these different fisheries. In the North American and European fisheries it is a commonplace for a vessel and her equipment manned by 10–20 men to cost US $ 2 000 000 or 100 000 to 200 000 dollars per crew member. Many artisanal or small-scale fishermen have an operating capital of US $ 1 000 or less and this would include the equipment required for preparing the fish for market. The shore-side backup in the North American and European fisheries is as expensive as the equipment required for fish catching.

These factors all have implications when one is considering how a fishery should be developed. Efficiency in the sense of best use of finance might require that large vessels should operate from modern ports employing sophisticated fishing methods and equipment and that these should be manned by highly trained crews. Common sense suggests, however, that those responsible for development must also consider the lot of the numerous small-scale fishermen who could be driven out of employment if too much emphasis is suddenly put on modernisation of the fishing industry. Even in cases where employment is not directly affected, the sudden arrival on the market of very large quantities of fish could, and indeed often does, depress prices to a level which makes it difficult for the small boat fishermen to survive.

UTILISATION

As we have already noted the fisheries make an important contribution to the national larder, providing animal protein which is of great nutritional significance and varies what would otherwise be a monotonous diet. From the enormous variety of fish which can be caught, it is possible to make a great range of products of different types which have very different keeping qualities and which may be used in a variety of different dishes. Some of the products, particularly those of highest value, may also be of importance in producing foreign exchange when they are exported. In the immediate area of Indonesia there has traditionally been a great volume of trade in fish products. Dried and fermented products traditionally travelled, in both directions, between Indonesia and countries as far as field as Thailand, in order to meet the differing needs of the populations. For many years, other products, such as beche-de-mer, shark fins and fish maws, have been exported to China and countries in which there is a large Chinese population. The newer export industries, particularly those involved in the production and marketing of crustacean products and frogs legs, require a very much higher level of technological expertise and we shall be looking at some of the different technologies required later in the course.

One point which should be mentioned at this stage is the effect that the fishing method used has on the quality of the fish. The amount of exercise a fish undergoes immediately before death, the length of time it is kept at different temperatures once dead, and its physiological condition all affect the state in which it will be when it reaches the consumer. Fish caught in a grill or drift net may spend up to 12 hours dead in the net before it is boated by a fisherman. Such fish will be nearly putrid when the fisherman gets it, other fish from the same net, gilled a few minutes

before boating, may well still be alive; there may thus be a need to sort a drift net not only into species but into fish in varying stages of post-mortem deterioration. A purse seiner may catch up to 100 tonnes of fish within a few minutes; it is impossible to gut and ice catches of this kind and, therefore, special methods of handling have to be developed. Fish caught at the end of a 3-hour trawl may have been swimming in front of the net for 2 hours or more before they fell back into it exhausted. Such fish, in which the glycogen reserves have been used up, will be very different from similar fish caught by hand lining. The processing technologist must thus know something of methods of fish capture and the effects that these are likely to have on the raw material he receives. So it is important that the technologist should not regard his own subject as being isolated from the catching and handling of the fish at sea. More than this, he must also be conscious of the end use to which the fish he handles will be put. He must be aware of market trend and consumer preferences.

One further point must be borne in mind when dealing with new or so-called virgin fisheries. The fish produced in these fisheries will often be larger, older, more heavily parasitised and even tougher to eat than the fish which will be caught once these big fish have been creamed off. The technologist should be constantly on guard about making too many assumptions about the raw material with which he has to deal.

Fish as food material: chemical aspects

This session will deal with the chemical constituents which go to make up fish and the methods used for the estimation of the basic chemical components. However, before we look at these constituents it will be useful to refresh our memories with a little basic chemistry.

ELEMENTS, ATOMS AND MOLECULES

Matter is composed of elements, of which more than 100 are known. An element is a substance which cannot be split up into anything simpler by chemical methods; elements can only be changed by using enormous amounts of energy, as when the methods of atomic physics are used. Some elements, like carbon and copper, are solids, some are liquids such as mercury and bromine, some are gases, such as hydrogen, oxygen and nitrogen. The chemist also divides these into metals and non-metals.

The smallest particle of an element which can take part in a chemical reaction with another element is called an atom; this is the smallest particle which can exist without losing the chemical identity particular to the element concerned. Most elements do not exist singly or free in nature, usually two or more are found in combination as compounds. Compounds are substances containing two or more elements combined so that their properties are changed. Thus oxygen and hydrogen can be mixed together to form a gaseous mixture but, if combined in proportions of two atoms of hydrogen to one of oxygen chemically, they will form a new substance, a compound called water. The smallest part of a substance, whether an element or a compound, which can exist in a free state is called a molecule. When atoms combine to form a molecule of a particular pure substance they always combine in the same fixed proportions. The number of atoms of hydrogen which will combine with or be displaced by one atom of an element is called the valency of that element. Oxygen has a valency of 2, nitrogen 3, carbon 4. Thus water always consists of 2 atoms of hydrogen combined with 1 of oxygen, carbon dioxide is 2 atoms of oxygen combined with 1 of carbon.

It would be cumbersome to always write out these reactions in full and the elements have been given symbols so that a form of shorthand can be used. Sometimes single capital letters are used, sometimes one capital and one small letter; thus carbon is C, oxygen O, hydrogen H, nitrogen N, sulphur S, iron Fe, lead Pb, sodium Na and chlorine Cl. Many of the symbols are shortened forms of the Latin name of the element; thus iron (ferrum) is Fe. These symbols are combined into molecular formulae which can be used to describe single substances or to describe how they react together. Thus, H_2O represents water, HCl hydrochloric acid. Simple formulae are less useful when more complicated substances are under consideration; thus the simple sugars of glucose and fructose both have the formula $C_6H_{12}O_6$, yet they are different substances. This is due to the different arrangement of the atoms within the molecule, such arrangements being represented by structural formulae.

Inorganic chemistry is the branch of science concerned with the study of substances that do not contain carbon-hydrogen bonds. Important groups of compounds are the acids, salts, bases and alkalis. Organic chemistry is concerned with compounds which do contain carbon-hydrogen bonds; these include the substances of which living matter is made and the term 'organic' comes from organ, it being thought at one time that carbon compounds could be formed only by living matter.

The substances which can be used as foods include carbohydrates (compounds which contain carbon, hydrogen and oxygen) and proteins which differ in that they all contain nitrogen in addition to carbon, hydrogen and oxygen. In the carbohydrates (sugars, starches, cellulose), hydrogen and oxygen are always in the proportion in which they occur in water, that is 2:1 and carbohydrates can be represented by the general formula $C_x(H_2O)y$. Thus sucrose, the sugar we buy in shops, also known as cane sugar, is $C_{12}H_{22}O_{11}$. When combined with water in the presence of a dilute acid and warmed, this breaks down to give 1 molecule of glucose and 1 molecule of fructose. Proteins consist of substances called amino acids (nitrogen-containing acids) in various combinations. Some of these can be converted into other amino acids in the body so that a shortage of a particular amino acid in the diet may not be too important. Other amino acids cannot be made in the body in this way and these are known as essential amino acids.

A third important organic group which occurs in living tissue are the oils or fats. Oils differ from carbohydrates in that the oxygen and hydrogen are not combined in the same proportions as in water. Oils consist of compounds of glycerol and various fatty acids; most contain acids which have at least one double bond between two of their carbon atoms, i.e. they are unsaturated. Fish oils are largely of this type. Such unsaturated acids combine readily with oxygen and substances called peroxides are formed. Oxidised oils are known as rancid oils; these are indigestible and may be poisonous to an animal which consumes them. Oils and fats can be used as energy sources by living things since they contain large quantities of carbon and provide more energy per pound than carbohydrates. Fat is thus a particularly useful way of storing potential energy and fish and most other animals store fats rather than carbohydrates; relatively small quantities of glycogens or animal starch are stored in the liver for use as a rapidly available source of energy. Plant material tends to store energy in the form of carbohydrate rather than as fat.

FISH FLESH COMPONENTS

Fish flesh contains four basic ingredients in varying proportions: water, protein, fat and minerals. As has already been mentioned, animals tend to store energy in the form of fat rather than as carbohydrate and the quantity of carbohydrate found in fish flesh is usually negligible, although some shellfish, notably oysters, can contain up to 8 per cent carbohydrates (chiefly as glycogen) in their meat.

Flesh from healthy fish contains from 60–84 per cent water, 15–24 per cent protein and from 0.1–22.0 per cent fat. Minerals usually constitute 1–2 per cent. The extremes mentioned are rarely met in practice and most fish contain from 70–80 per cent water. The proportions of the constituents are species specific and the main variations between species are in the fat content. Indeed fish are often classified according to their fat content. Lean fish have less than 0.5 per cent fat, semi-fat fish contain 0.5–2 per cent fat and fatty fish have more than 2 per cent fat. None of the important tropical fish are truly lean, most being in the semi-fat category. Clupeoids, mackerels, tunas etc. are in the fatty group. It is characteristic of many of the fatty species such as herring that they have a seasonal variation in fat content. In starved United Kingdom winter herring (*Clupea harengus*), fat content may be as low as 0.5 per cent but as high as 20 per cent in well-fed summer herring. In general the seasonal variation in fat content is accompanied by an inverse variation in the amount of moisture in the flesh. This means that for a particular species the sum of the fat and water content is more or less constant.

Protein content tends to vary much less widely from one species to another and there is generally little variation from season to season in a particular species. Most fish contain approximately 20 per cent protein but it can vary between 10 and 24 per cent. In general, bivalve molluscs contain only about 10 per cent protein in their flesh which is much lower than most other marine organisms of commercial importance.

ANALYSIS OF MAJOR COMPONENTS

Fish and fish products consist of moisture, fatty substances, protein and inorganic salts. Consequently the most frequent analyses on fish are for moisture, crude fat, crude protein and crude ash. When done by customary chemical procedures, this group of analyses is frequently referred to as proximate analysis.

Whenever practicable, the generally accepted or official methods of analysis should be chosen or results of other procedures should have some definite reproducible relationship to the results from official analysis. The Association of Official Agricultural Chemists (AOAC) have documented a useful set of official analyses.

Moisture

Moisture in fish products is commonly determined by drying a sample at some elevated temperature and reporting the loss in weight as moisture. The length of time, temperature and pressure during the drying process are different for various methods. Since all the methods are empirical, care must be taken to follow the directions exactly if precise and reproducible results are to be obtained. Every precaution must be taken to avoid moisture loss when the sample is weighed out in the initial instance, or moisture adsorption when the dried residue is weighed after drying. Time of drying will be especially important in those methods that use a high drying temperature (120°C or higher). Results obtained at different drying temperatures are not precisely the same; therefore, values from different methods may vary significantly.

Conventional oven drying moisture determinations under atmospheric pressure may take up to 24 hours. The weight loss/moisture measurement may be speeded up with the use of a direct heat source incorporated with the weighing device, or in the combination of mild heating and reduced pressure as in a vacuum oven technique.

Fat

The more precise methods for determining crude fat in fish and fish products involve extraction of fat from a dried sample with anhydrous ethyl ether or petroleum ether. After extraction, the solvent is removed from the sample by evaporation. The residue is then weighed and reported as fat. These methods are often referred to as Soxhlet determinations and several precautions must be observed when using them. If ethyl ether is used it must be anhydrous and the sample extracted must be free of moisture; otherwise some water soluble material will be extracted and reported as fat. Samples used for fat extraction should be dried at temperatures below 125°C to avoid changes that may prevent extraction of the fat. The flasks and beakers used in the fat extraction should be carefully cleaned, dried and weighed before the extraction; they must be dried and weighed under exactly the same conditions after the extraction has taken place. Complete directions for fat analysis by these methods are available at TPI.

Protein

The most universally accepted method for determining total nitrogen or crude protein in fish is the so-called Kjeldahl method. This involves the oxidation of organic matter with sulphuric acid in the presence of a catalyst and then the simultaneous formation of ammonium salts and amines from the nitrogen components in the fish. The solution is made alkaline and the amines and ammonia

distilled into standard acid. The solution is then back-titrated with standard alkaline and the amount of nitrogen as ammonia calculated. The nitrogen value is multiplied by 6.25 to give a value for crude protein. However, this value includes all volatile base material including nitrogen-containing compounds which are not proteinaceous. Studies on this method and the generally accepted published procedures stress the following points:

1. The use of a good catalyst.
2. The proper amount of sodium sulphate or potassium sulphate to raise the boiling point of the sulphuric acid to the necessary level during digestion.
3. Proper digestion temperature and time (at least 2 hours).
4. Careful and complete distillation of the ammonia and amines into an adequate amount of standard acid or boric acid receiver.

Ash

Ash in fish and fish products is readily determined by incineration of a dried sample at about 525°C for 6–18 hours, depending on the method used. The residue is weighed and reported as ash. Care must be taken to oxidise all the carbon during the determination. It is sometimes necessary to add refined vegetable oil to the ash and continue the incineration for several hours to obtain a pure white ash.

Fish as a food material: nutritional aspects

Foods perform three quite different functions:

1. They provide energy by the process known as respiration which is essentially the same as burning.
2. They are used for body building.
3. They provide protection; this includes the regulation of body processes.

The science of nutrition is the study of all processes of growth, maintenance and repair of the living body which depend upon the digestion of food and the study of that food.

Food is any solid or liquid which can supply any of the following:

(a) material from which the body can produce movement, heat, or other forms of energy,

(b) materials for growth, repair, or reproduction,

(c) substances necessary to regulate the production of energy or the processes of growth and repair.

The diet consists of those foods or mixtures of foods in the amounts which are actually eaten (usually measured each day); a balanced diet contains adequate amounts of all the nutrients.

The following types of nutrients may be present in foods:

Carbohydrates, which provide the body with energy and may also be converted into body fat.

Fats, which provide energy in a more concentrated form than carbohydrates and may also form body fat.

Proteins, which provide the materials (amino acids) for growth and repair. They can also be converted into carbohydrates and used to provide energy.

Minerals, which are used in growth and repair and help to regulate body processes.

Vitamins, which help to regulate body processes.

Note that vitamins differ from hormones (which also help to regulate the body processes) because they cannot be made in the body and must therefore be supplied in the food. Hormones are always made within the body.

Although water, like oxygen from the air, is also essential for life, it is not usually considered to be a food or a nutrient. Alcoholic drinks on the other hand are foods because they provide energy, although alcohol has drug-like properties. Very few foods contain only one nutrient; most are very complex mixtures, consisting of a variety of carbohydrates, fats and proteins, together with water; minerals and vitamins are present in much smaller amounts. Fish is thought of mainly as a source of protein but the fattier species also contain appreciable quantities of energy-giving fat.

Fish contain large quantities of all the minerals which are important in the human diet, but, when a fish is filleted and the head, bones and skins are discarded, much of the mineral content is lost. Almost all the calcium and phosphorus present in the fish are within the skeleton. Small fish, however, are often eaten whole and then the mineral content of the skin and bones can be important. When canned fish is eaten, of course, the softened bones are usually eaten as well as the flesh and then the mineral content is not wasted.

THE PROVISION OF ENERGY

Although we are concerned mainly with fish and fish products as a source of protein for body building, an elementary understanding of the way energy is provided is also useful. The amount of energy used by a man in carrying out his normal daily tasks can be measured in the form of the heat produced; this used to be done by confining people in a small room. It can also be done by measuring the oxygen used and the carbon dioxide formed or by measuring the energy content of the food eaten.

Table 1

Energy expenditure in kilocalories per minute for a 70 kg (154 lb) adult

Daily activities		*Maximum efforts*	
Washing and dressing	2.6–3.0	Planing hardwood	9.1
Walking: 3.2 km/h	2.9	Shovelling earth	10.3
5 km/h	4.0	Sculling at 97 m/min	11.2
6.5 km/h	5.2	Swimming at 55 m/min	14.0
Sitting	1.5	Climbing with a load	13.2
Sitting and writing	2.0	Skiing uphill	18.6
Driving a car	2.8	Walking in loose snow	20.2
Riding a motor-cycle	3.4		
Sweeping the floor	1.7		
Ironing	4.2		
Polishing the floor	4.8		
Recreation		*At work (engineering)*	
Cycling: 9 km/h	4.5	Light (draughtsmen, drilling, light assembly)	1.8
15 km/h	7.0		
21 km/h	11.1		
Digging	8.6	Medium (turners, joiners, toolroom workers)	3.8
Playing tennis	7.1		
Playing football	8.9		
Cricket: fielding	3.9	Heavy (loading, casting, machine fitting)	4–7
bowling	5.2		
batting	6.0		

From: Passmore and Durnin (1955). *Physioligical Review 35,* 801

A kilocalorie (kcal) is the amount of heat needed to heat one litre of water by 1°C. Carbohydrate foods, that is starches and sugars, and also proteins provide 4 kcal/g. Fats provide a more concentrated source of energy and supply 9 kcal/g.

In a living man energy is used up to keep the body warm, to keep the muscles active and to keep the heart beating and the organs functioning. This energy requirement is called the basal metabolic rate (BMR) which is measured when the person is inactive. The BMR is approximately one kcal for each kg of body weight in each hour, so an average 70 kg adult needs about 70 x 24 = 1 680 kcal/day in order to exist without undertaking any activity. The BMR varies with age and sex as well as with body size. It remains constant for any particular person but the remainder of the energy he uses depends on what he does. Table 1 illustrates this point. People who do very heavy work may use as much as 4 500 kcal/day while a clerical worker may use only 2 500.

The body stores energy as glocogen and fat. The liver may contain about 100 g of glycogen, the muscles another 500 g, so that these store 2 400 kcal which would last for about 1 day. Depending on whether a person is thin or fat, the fat store may vary from 10 kg to over 100 kg; the thin person would be able to live for some 40 days without food, the fat one for well over a year.

PROTEIN IN THE DIET

All proteins are compounds of carbon, hydrogen and oxygen but, unlike carbohydrates and fats, they always contain nitrogen as well. Most proteins contain sulphur and some contain phosphorus. They are essential constituents of all animal cells, where they regulate the processes of living or provide structure. Protein must be provided in the diet for the growth and repair of the body but any excess can be converted into glucose (a sugar) and used to provide energy.

Protein consists of chains of hundreds or thousands of amino acid units. Only about 20 different amino acids are used but the number of ways in which they could be arranged is almost infinite. It is the specific and unique sequence of these units which gives each protein its characteristic structural and enzymatic properties.

The amino acids can be conveniently divided into two types; the essential amino acids which cannot be made in the body, at least in amounts sufficient for health, and must therefore be present in the food, and the non-essential amino acids which differ only in that it is possible for them to be made from any excess of certain other amino acids in the diet. The eight amino acids essential for adult humans are: isoleucine, phenylalanine, leucine, threonine, lysine, tryptophan, methionine, and valine. Histidine is also essential for the rapidly growing infant. Other amino acids common in proteins are: alanine, glycine, arginine, proline, aspartic acid, serine, cysteine, tyrosine and glutamic acid.

The quality of a protein depends on its ability to supply all the essential amino acids in the amounts needed. Thus wheat, which is comparatively low in lysine, maize, which is low in tryptophan, and legumes, which are low in methionine, are said to be of low biological value. Animal proteins, including those in fish, have a high biological value as would be expected since the proteins of animals are more like those of man than those of vegetables. Mixtures of vegetable foods can, however, complement each other and provide adequate quantities of the essential amino acids.

During digestion, the proteins are broken down to amino acids. The first action takes place in the stomach where the food is mixed with gastric juice, which is very acidic and contains the enzyme pepsin; the activity continues in the small intestine where pancreatic juice neutralises the acid material and where trypsin and chymotrypsin continue to break down the proteins into small peptides and amino acids.

The peptides may enter the intestinal wall where they are split into amino acids which are carried in the blood directly to the liver. From the liver, they are passed into the general circulation where they enter the body's pool of essential and non-essential amino acids. These are then built into the structural protein and specific enzymes which each cell needs. The excess of some amino acids may be converted into certain others. Any remaining excess of amino acids is oxidised for energy, in some cases after conversion into glucose; urea is also formed and excreted through the kidneys. If the diet as a whole is inadequate in energy, then a greater proportion of the protein will be used for this purpose in order to keep the body alive.

It is easy to understand that growing children require protein in order to build their bodies since the bodies become visibly larger month by month. It is less easy perhaps to understand that adults need to replace worn out tissues. Living tissues are continually worn out and replaced by new tissues; this is called dynamic equilibrium. The liver, blood serum, heart and kidneys are all very active organs which are broken down and replaced at such a rate that half the organ is renewed in 10 days, i.e. they have a half life of 10 days. The muscles, bone and skin do not break down so readily and have a half life of 158 days. The proteins of the body as a whole have an average half life of 80 days. So protein is essential for all animals whether they are growing or adult. Since children require protein both for replacement and for growth their minimum requirement is 1.4 g/kg of body weight as compared with 0.45 g for an adult man.

An adult can maintain reasonable health on a supply of protein that would be quite inadequate for a child. A 4-year-old child weighing only 17 kg needs almost the same minimum intake of protein as an adult – 25 g/day. As the child normally eats only half as much food as an adult his diet must contain a much higher proportion of protein. The British Department of Health and Social Security recommends that an active man should take in 90 g of protein per day, the minimum requirement being 45 g. The recommended allowance for adult females is lower, at a recommended 63 g per day, with a minimum requirement of 38 g. Requirements for lactating females are somewhat higher at a recommended 68 g and a 55 g minimum requirement. Actively growing teenage children need as much protein as the most active man. Such recommendations need to be considered with care since, as we have seen, the amino acid mixture of different proteins can vary quite widely.

It is important to realise that although we talk of fish and meat as being protein foods, most vegetable foods also contain some protein and some contain quite large quantities. Rice, for example, contains between 6 and 8 per cent protein. Not all protein is of the same quality, of course. A protein which has the essential amino acids in the same proportion as they are present in the human body is of high quality and is said to have a high biological value (BV). The nutritive value of a protein food is a combination of quantity and quality; thus a large quantity of low quality food can be as good as a smaller quantity of high quality protein food. In general there are two methods of measuring the quality of protein; the first method measures growth in relation to the amount eaten, which is defined as the Protein Efficiency Ratio (PER). The second is a measurement of the amount of protein in the diet that is retained in the body for useful purposes. The amount retained is sometimes expressed as a percentage of the protein in the diet; the term used then is Net Protein Utilisation (NPU). When the amount retained is expressed as a percentage of the protein taken in, that is to say, when the part which is not digested is ignored, the term used is Biological Value.

Thus NPU = BV x Digestibility

PER values range from 0 to 4.0. BV and NPU values are expressed as percentages.

Table 2 lists a number of stable foods with their NPU values. The animal protein foods generally have higher NPU values as would be expected. It will be seen that some plants are useful sources of protein, while others such as cassava and sweet potatoes contain very little indeed. This does not mean that plant proteins cannot be useful in the diet.

Table 2

Protein	Net Protein Utilisation	% Calories from protein	% Crude Protein content
Animal protein foods			
Fish (cod fillet)	83	85	16
Beef	72	38	15
Eggs	91	29	12
Cheese	70	24	25
Milk	75	20	3
Plant protein foods			
Sunflower seed	54	21	28
Peas	39	29	26
Sesame (dehulled seeds)	58	17	24
Beans	32	25	22
Groundnuts	45	18	25
Wheat flour	50	14	12
Millet	50	12	10
Maize	49	11	10
Rice	70	8	7
Poor protein sources			
Yams	50*	9	2.1
Sweet potatoes	50*	7	1.3
Taro	50*	7	1.5
Bananas	50*	5	1
Breadfruit	50*	5	0.6
Plantains	50*	4	0.8
Cassava – fresh	50*	3	1
– flour	50*	2	1.5
Protein concentrates from animal sources			
Egg – defatted, dried	91	90	85
Fish meal	75	88	75
Casein – crude	60	95	90
Milk, dried skim	75	43	35
Protein concentrates from plant sources			
Soya flour	56	71	46
Cottonseed meal	59	62	58
Yeast	40	87	45
Groundnut flour	45	67	54
Sesame flour	58	49	46

*NPU measurements at such low protein levels are very unreliable: the value is taken as 50.

Source: The relative merits of plant and animal proteins, A. E. Bender in: 'The Better Use of the World's Fauna for Food', Symposia of the Institute of Biology, No. 11. London: Institute of Biology, 1963.

Mixtures of plant proteins can be prepared which have higher NPU than the arithmetic mean of the components. This is because deficiencies in one protein can be made good by a surplus of the amino acid in the other proteins of the mixture. This is explained in Table 3.

Table 3

Complementation between pea and maize

	Yellow pea flour	Maize meal
Biological Value	43	35
Lysine	5.6	2.6
Methionine + cystine	2.0	5.3
Mixture of 2 maize: 1 pea flour		
Biological Value		
(a) arithmetic mean	39	
(b) calculated from amino acids	72	
(c) determined	70	

Source: The relative merits of plant and animal proteins, A. E. Bender, in: 'The Better Use of the World's Fauna for Food', Symposia of the Institute of Biology, No. 11. London: Institute of Biology, 1963

The result is due to the fact that the maize has very little lysine but is rich in the sulphur amino acids and reasonably good in its contents of the other essential amino acids, whereas pea flour is low in the sulphur amino acids, rich in lysine and has reasonably high contents of the other amino acids. A mixture of 2 parts of maize to 1 part of pea flour produced the results illustrated. Since proteins are used to manufacture body tissue, they can only be as useful for this purpose as the essential amino acid present in the smallest quantity. This is called the limiting amino acid. Plant proteins are generally limited by their lysine content, animal proteins by their methionine content. Mixtures of plant and animal protein are therefore very useful and it is desirable that some part of the mixture should include animal protein. In Britain we get about one third of our protein from the bread flour and cereals we eat, meat provides about one quarter and milk almost a fifth. The remainder is provided by potatoes and other vegetables, as well as the high protein foods, cheese, fish and eggs.

FATS

Fats are solid at low temperatures and become liquid (oil) when they are heated. Oils are simply fats which are liquid at room temperature. Fat makes an important contribution to the texture and palatability of food. The amount of energy obtained from all common fat is about the same, despite the different functions of many of the component fatty acids. Animals, including man and fish, store excess energy almost entirely in deposits of fat, the amount of which is very variable. Fish such as mackerel, sardines, tuna and eels are called fatty fish, the proportion of fat in them varying with the season of the year. Immediately before spawning fish build up a high reservoir of fat. This is used up and immediately after spawning the fattiest of fish can be quite lean. Fish can contain up to 20 per cent fat.

Fats usually contain small amounts of other fat soluble substances including flavour components and some of the vitamins. These include retinol (vitamin A) and vitamin D and varying amounts of cholesterol. While some fish store their fats in depots in the body, others store their oil mainly in the liver. Such oils contain high quantities of vitamins A and D. Vitamin A is essential for vision in dim light; prolonged deficiency results in night blindness. In children in many parts of the world, deficiency also results in severe eye lesions (terophthalmia) and complete blindness. Vitamin A is also necessary for the maintenance of healthy skin and surface tissues, especially those which excrete mucus. Excessive doses, for example from taking a large amount of vitamin A preparations for long periods, accumulate in the liver and can be poisonous. Vitamin D regulates the level of calcium and phosphorus in the blood. Children who take in too little vitamin D develop rickets in which the bones are deformed and may become too weak to support their weight. These changes readily become permanent so it is important to prevent their development. Too high an intake of vitamin D causes more calcium to be absorbed than can be excreted; the excess is then deposited in the kidneys which it may damage. Fish are not generally an important source of the water soluble vitamins B, C and K.

MINERALS

Most of the inorganic elements or minerals can be detected in the human and fish body but only about 15 of them are known to be essential to man and thus must be derived from his food. Minute amounts of a further five or more are necessary for normal life in some animal species and may yet prove to be necessary for man. Minerals have three main functions:

(a) As constituents of the bones and teeth. These include calcium, phosphorus and magnesium.

(b) As soluble salts which help to control the composition of body fluids and cells. These include sodium and chlorine in the fluids outside the cells (for example blood) and potassium, magnesium and phosphorus inside the cells.

(c) As essential adjuncts to many enzymes and other proteins, such as haemoglobin, which are necessary for the release and utilisation of energy. Iron and phosphorus and most of the other elements act in this way.

EFFECTS OF COOKING AND PROCESSING FISH

Heat causes the proteins in the muscle fibres to coagulate; the flesh becomes firmer, some shrinkage occurs and there is extrusion of juices and loss of weight. Weight loss is generally of the order of 15 per cent. The vitamins A and D present in fatty fish are both heat stable. Cooking makes fish flesh more easily digestible.

In preparing fish for most processes, there are trimming losses: in filleting, for instance, about 30–50 per cent is separated as edible flesh but a considerable amount of edible flesh is left on the bone. Similarly, losses may occur when large fish are cut for salting and drying or when any fish is canned.

Drying and smoking both result in weight losses due principally to loss of water rather than of nutrients. In effect the protein is concentrated.

During salting there is a loss of weight from two causes. Water is drawn out and some protein is dissolved into the brine; other nitrogenous substances, including free amino acids, are also lost. The quantity of protein lost depends on the exact nature of the salting process – whether it is a wet or dry process and how long it lasts. When salting herring, the protein content has been known to fall from 21 to 16.5 per cent. Water soluble vitamins are also lost. Oil losses are usually negligible. There is little in the literature about protein loss during salting processes in the tropics. Where salting is in preparation for sun drying, it often lasts only 24 hours or so. Weight loss (water plus soluble substances) is of the order of 10–15 per cent. The quantity of nitrogenous substance lost in salting depends to a high degree on the condition of the fish when salted. Spoilt fish lose more than fresh fish. This suggests that losses may be heavy when fermented fish is made.

Nutritional damage due to heat processing is still not well understood. Heat damage to protein may be due to the direct destruction of some amino acids or it may result from the Maillard reaction in which linkages are formed between the amino groups of the amino acids and other foods such as sugars. Lysine, in particular, may be rendered unavailable to a man eating the fish because the digestive enzymes cannot break the linkages formed during the Maillard reaction. The loss of available lysine during fishmeal manufacture is well known; feed compounders now request analysis for available lysine as a routine before buying. Even the heat produced by traditional African hot smoking processes (up to 112°C) can cause damage, from 7 to 33 per cent of available lysine being lost. An interesting finding during research on this topic was that the oil content of the flesh rose from 6 to 15 per cent (dry weight basis) during smoking, presumably because fat from the body cavity melted and flowed into the flesh.

Rancidity causes fats to become unavailable to a consumer. Some salting processes enhance the rate at which oxidative rancidity takes place. Sun drying accelerates rancidification, which is one of the reasons for recommending shade drying where practicable.

The physical structure and chemical composition of fish

PHYSICAL STRUCTURE

True fish

The true fish may be sub-divided into two types:

(i) those that have bones, i.e. the majority of species caught;

(ii) those that have cartilage instead of bones, e.g. shark, skates, rays and some deep sea species – some bear their young alive.

In most other respects the two types are similar. The outer layer is a skin, often covered with scales. The skin thickness varies with species, showing a range of at least 0.3 to 1.1 mm. The skin is reputed to be thicker in aggressive species and to thicken when the fish is not feeding; *post mortem* its strength is determined by thickness and pH value. Often the skin is eaten (perhaps after removal of the scales by scraping) but sometimes it is used as a by-product e.g. shark skin. The skin contains some 16 per cent protein, a little fat and minerals and some 80 per cent water.

Figure 1
Outline drawing of vertical sections through a typical demersal fish and a typical pelagic fish showing relative amounts of light and dark muscle.

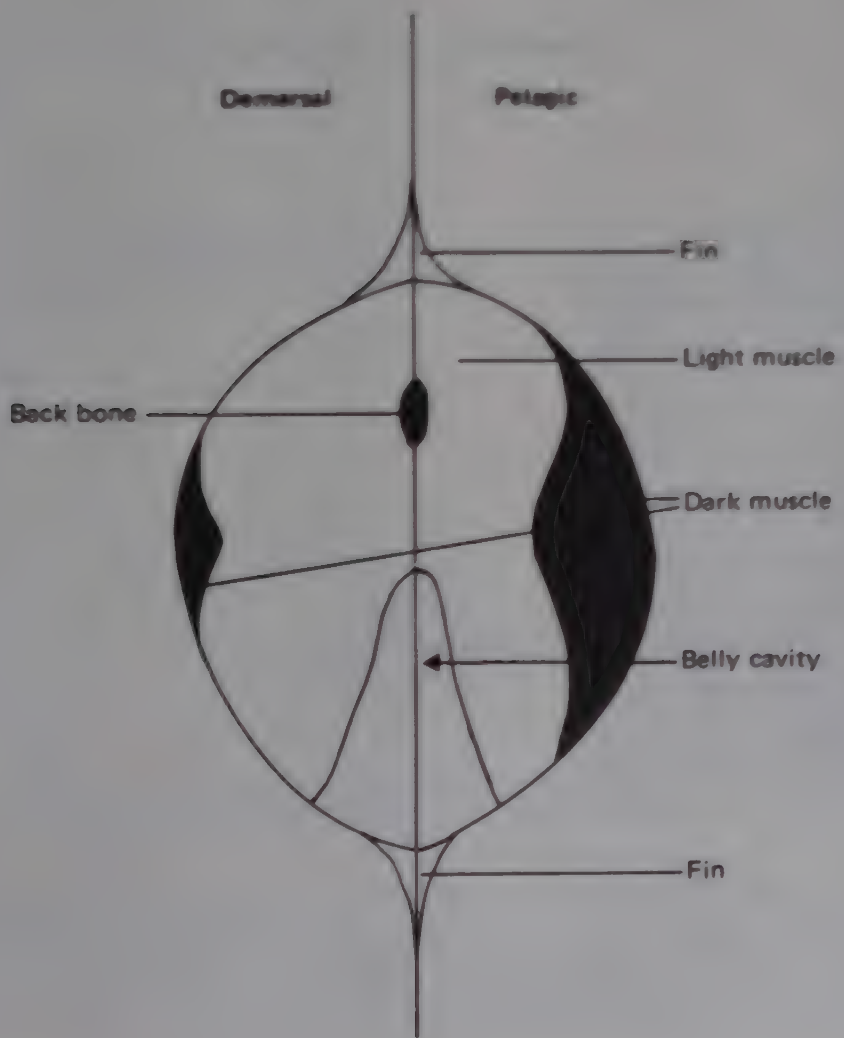


Figure 2
Outline drawing of Atlantic cod *(Gadus morhua)* with part of skin together with some superficial muscle removed to show arrangement of muscle blocks (myotomes) and connective tissue sheets (myocommata).

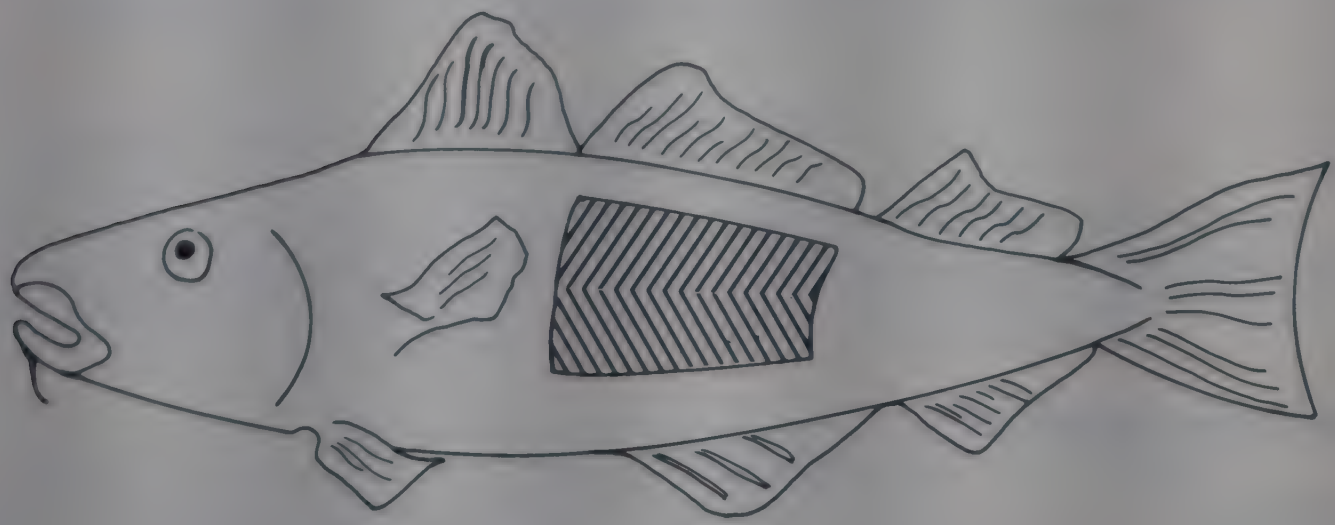


Table 1

Typical yield of edible flesh and organs as percentage fresh weight

Species	Head	Viscera	Liver	Flesh
Pacific herring (*Clupea pallasi*)	8 – 18	6 – 21		42 – 65
Coho salmon (*Oncorhynchus kisutch*)	8 – 11	11 – 17	1½ – 2½	71 – 75
Pacific hake (*Merluccius productus*)	15 – 30	7 – 15		47 – 58
Skipjack tuna (*Katsuwonus pelamis*)	11 – 26	7 – 23		61 – 66
Pacfic cod (*Gadus macrocephalus*)	19 – 25	11 – 28	4 – 7	39 – 48
Atlantic cod (*Gadus morhua*)	21	5 – 8	2 – 7	39 – 49
	also Roe 1 – 7% and backbone approx. 14%			
Crab (*Cancer pagarus*)				27 – 36
Lobster (*Homarus* sp.)				44
Scampi (*Nephrops norvegicus*)				20 – 27
Indian prawns (*Metapenaeus dobsoni*)				41 – 44
(*Metapenaeus affinis*)				45 – 49
(*Penaeus stylifera*)				33 – 37
Oyster (*Crassostrea* sp.)				11 – 17
Scallop (*Pecten* sp.)				10 – 18
Squid (*Loligo* sp.)				60 – 80
Bream (*Tilapia mossambica*)		2 – 16		27 – 43
Mudsucker (*Labeo cangoro*)		2½ – 20		29 – 51
Tiger fish (*Hydrocyon vittatus*)		2 – 12		38 – 57
Barbel (*Clarias mossambicus*)	33 – 54 (guts and head)			27 – 49
Alumahon (*Rastrelliger chrysozomos*)				36 – 44
Bambongin (*Lutjanus fulicus*)				66
Tulingon (*Auxis thazard*)				64 – 71

In most species of fish, there is a layer of fatty tissue immediately below the skin which is usually red or black in colour. This layer is more pronounced in the pelagic species, where it expands in the region of the lateral line. (See Figure 1). In a few species this layer is replaced by a fat-rich blubber, e.g. spiny eel, and in some tuna

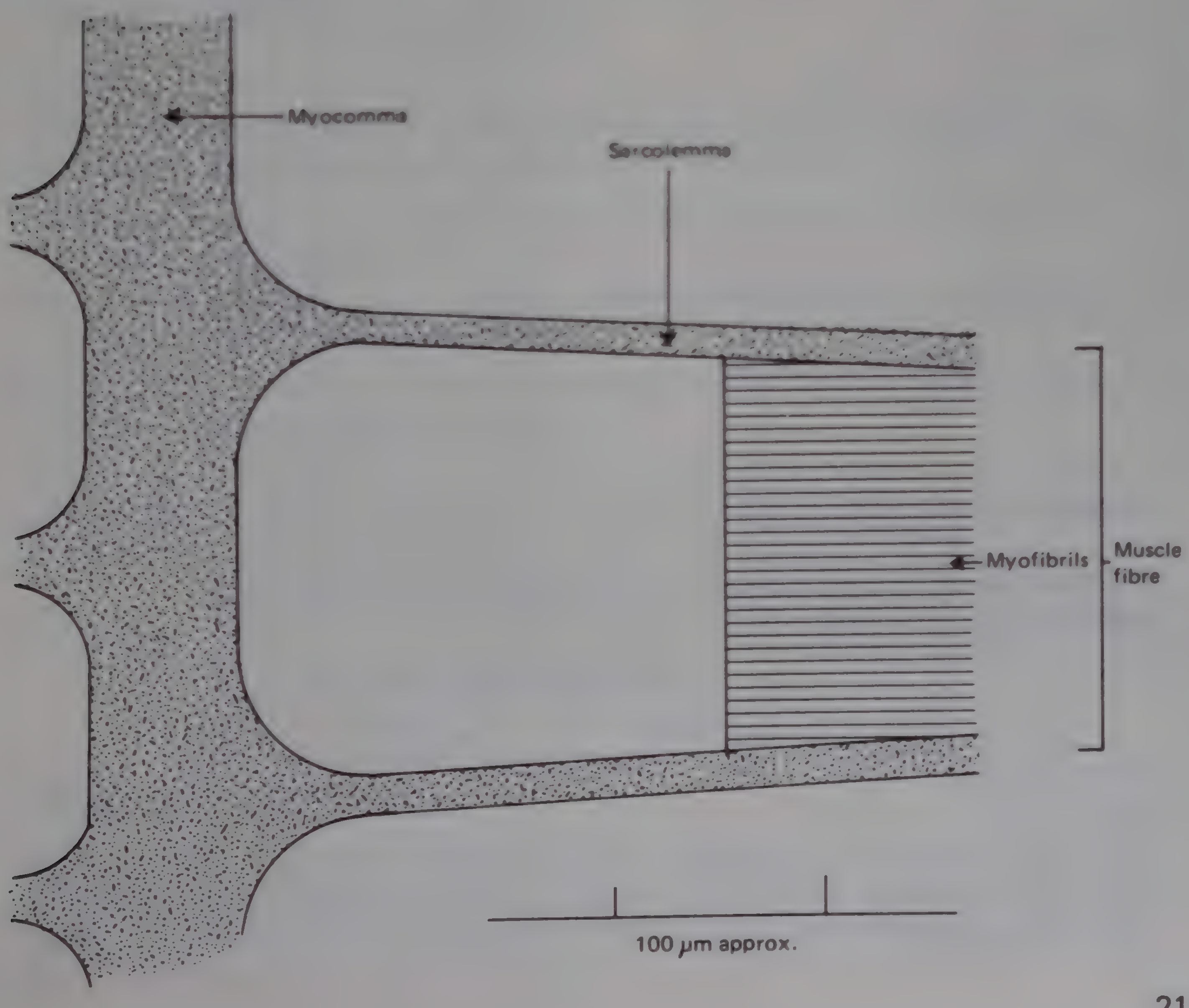
both layers occur. In a few species, this dark muscle layer is absent, e.g. white sucker (*Catostomus commersoni*) and spiny eel (*Notaconthus nasus*).

Internal to this layer (if present) is the ordinary muscle which is bounded internally by a skin-like layer called the peritoneum. This layer surrounds the body cavity in which are found the digestive organs, reproductive organs, liver and kidneys (see Figure 1).

In some species, the reproductive organs are of value not simply as food but as an expensive delicacy, e.g. caviar from various species of sturgeon and milt and roes from many other species. The liver may be minute but in certain species, e.g. Atlantic cod, the halibuts, sharks and rays, the liver may be large and rich in fat. These organs may be prized either for their oil content, which may be as high as 75 per cent, or for their high content of vitamins A and D, or for their content of sterol-related hydrocarbons (cartilagenous species).

In most fishing operations, however, it is the yield of muscle that is of most importance since this is the tissue most sought after as food (see Table 1). Muscle consists of sections containing contractile proteins surrounded by connective tissue that is attached in turn to the skeleton and to the skin. The connective tissue consists of sheets of collagen known as myocommata. The sections or blocks of muscle are known as myotomes (see Figure 2). These muscle blocks and the associated connective tissue sheets are visible to the naked eye. If the muscle block is magnified, i.e. examined microscopically, it is seen to consist of muscle fibres of between 150 and 300 μm diameter, surrounded by connective tissue, which is continuous with

Figure 3
Idealised outline drawing to show relationship between myocomma (connective tissue), sarcolemma (connective tissue), muscle fibre and myofibrils.



the main connective tissue sheets (see Figure 3). Further magnification shows that these muscle fibres consist of smaller fibres or myofibrils that are each 1–2 μm in diameter (see Figure 4). Each myofibril is divided lengthwise into a large number of identical units called sarcomeres (see Figure 4): these contain molecules of the main contractile proteins, actin and myosin; minor associated proteins, troponin, and tropomyosin; enzymes such as myosin-ATPase; and many other components.

As mentioned previously, most true fish contain two types of muscle – dark (black or red) and light (white or pale). These two types of muscle differ in their function and, slightly, in their microscopic size and structure, but these details are not of great importance to us. However, the dark muscle has a much higher fat content than the light muscle (see Table 4) and the ratio of dark to light muscle differs within a single fish as one moves from head to tail (see Table 2). There are other chemical differences, e.g. dark muscle usually contains more trimethylamine oxide and amino acids. These differences make it essential to ensure that samples for analysis are always taken from the same relative position and thus contain essentially the same proportion of light and dark muscle.

Figure 4
Idealised outline drawing of part of a myofibril to show part of one sarcomere and the relationship between actin and myosin

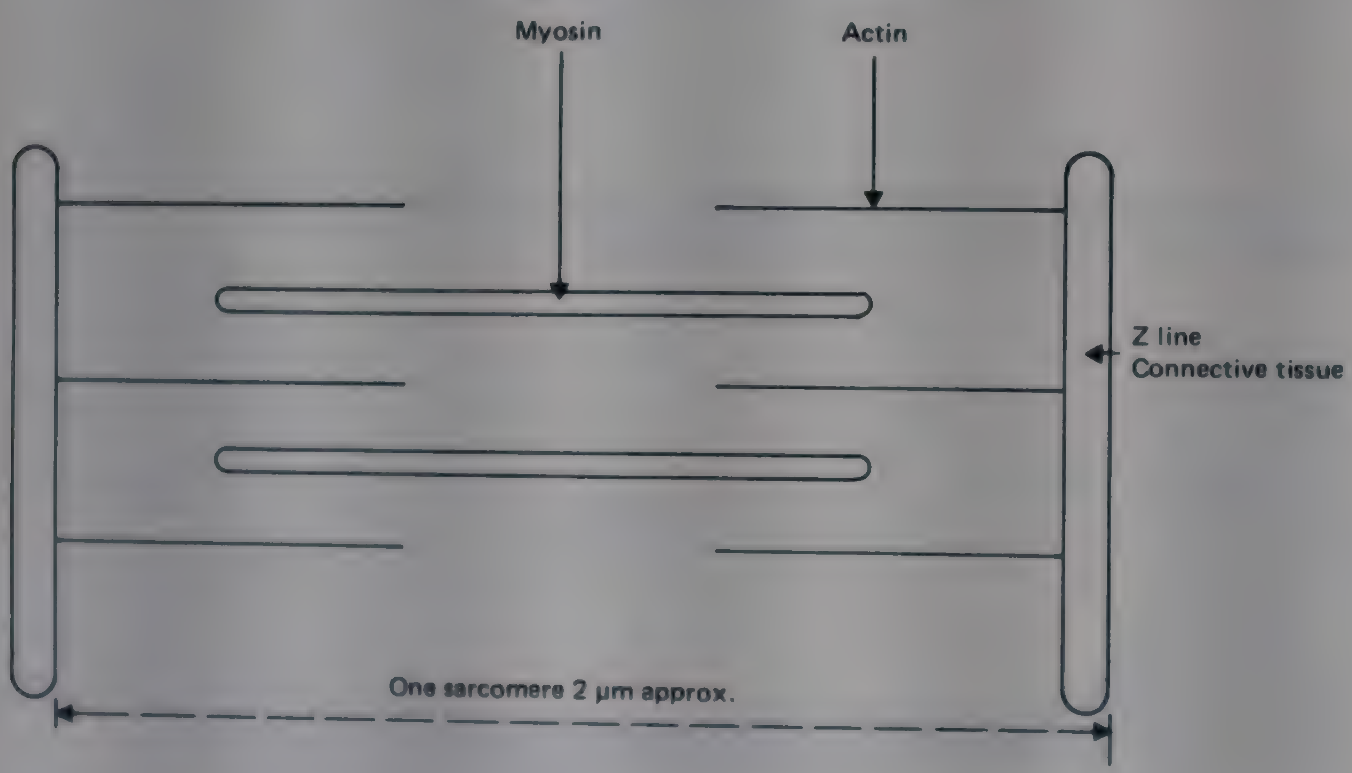


Table 2

Relative amounts of light and dark muscle at various body positions in several species of true fish

Species	Dark muscle as percentage of total muscle		
	Near head	Near middle	Near tail
Cod (*Gadus morhua*)	1	–	8
Atlantic Mackerel (*Scomber scombrus*)	11	–	27
Pacific Mackerel (*Pneumatophorus japonicus*)	8	–	29
Tuna (*Katsuwonus pelamis*)	9½	11	10

Crustaceans

Crustaceans differ substantially from true fish. The outermost layer, commonly called the shell, is an exoskeleton that supports and protects the softer parts of the body. This shell consists of modified protein and a polysaccharide known as chitin, and may be calcified. In some countries, notably India and the U.S.A., chitosan has been recovered from prawn shell in the hope that it can be used as a glaze for paper. This shell is shed at intervals and replaced by a new larger shell to accommodate the growth of the soft parts of the body. This moulting process (ecdysis) requires profound physiological changes in the animal which also influence its eating and processing quality, in particular its susceptibility to a discolouration known as black spot.

Within the shell is found a three-part body – head, thorax and abdomen. It is not always easy to distinguish the boundaries between these three sections, and even biologists do not always agree where one section ends and the next begins. It is sometimes said that it is the abdomen that is most prized for food but in many cases this may well include part of the thorax. It is probably better to use the terms head and tail, respectively, for the portions that are often discarded and those that are generally prized. In the larger species the walking or swimming appendages (legs) and feeding appendages (claws) may also yield a substantial amount of edible muscle.

This muscle is bounded externally by a pigmented layer that may conveniently be called skin but it is not the exact counterpart of the skin of the true fish. It is a heavily pigmented layer that may easily discolour post mortem. Crustacean muscle is similar but not identical in microscopic structure to the muscle of true fish, the fibres being larger and frequently branched. These structural differences in some way impart a more chewy texture than is normal for the flesh of true fish.

Strictly, the digestive system and reproductive organs are found in the thorax, but in practice the reproductive organs and posterior part of the gut (sandvein) may be taken with the edible portion or tail. Body meat incorporating the digestive gland or 'liver' is usually darker in colour (often brown) and contains more fat than the leg and claw meat which is relatively pale.

Molluscs

Edible molluscs may be sub-divided into three types, all of which are characterised by a mantle which in many cases is calcified and called a shell:

(i) *Bivalve molluscs* – have a shell opening in two parts, e.g. scallops, oysters, mussels, clams, cockles etc.

(ii) *Univalve molluscs* – have a one piece shell which is often coiled, e.g. abalone, winkles, whelks, conches etc.

(iii) *Cephalopod molluscs* – have a noncalcified mantle and a siphon for propulsion, e.g. octopus, squid, cuttlefish etc.

In each case it is normal to discard the guts but the muscle, liver and reproductive organs (roes) are eaten. After removal of the suckers and the flesh that is attached to the mantle of the cephalopod molluscs the tentacles are also eaten.

CHEMICAL COMPOSITION

Note that Table 3 contains selected values for a wide range of types and species of fish and their water, fat and protein contents. When using the tables, it is important to refer first to sections on water, fat and protein and Tables 4, 5 and 6 in the text which follows.

Water

Water is the major component of all species and types of fish. Typically, the content is in the range 70 to 80 per cent of the fresh weight although some deep water species may contain in excess of 90 per cent. There are seasonal variations, a slight increase occurring when the fish is starving (typically a rise of 1–2 per cent in demersal species but perhaps as much as 17 per cent in pelagic species). The water content may also rise slightly when fish are stored in melting ice or refrigerated seawater. For most bony fish, the fat and water content together approximate 80 per cent. In simple terms, it may be said that the high water content is responsible for the perishability of fish.

Table 3

Proximate composition of some fish from tropical areas*

Species	Composition (by percentages)†		
	Water	Fat	Crude Protein
Africa			
Bream (*Tilapia mossambica*)	74.5 – 83.7	0.1 – 8.4	14.0 – 20.6
Mudsucker (*Labeo congoro*)	75.1 – 83.6	0. – 6.1	15.2 – 21.2
Tiger fish (*Hydrocyon vittatus*)	74.7 – 80.2	0. – 3.5	18.5 – 23.4
Barbel (*Clarias mossambicus*)	75.2 – 84.6	0.2 – 6.3	13.0 – 18.5
Barracouda (*Sphyraena jello*)	76.5	0.7	20.0
Bonga (*Ethmalosa dorsalis*)	68.3 – 71.2	2.3 – 7.5	19.8 – 20.8
Sea bream (*Pagelus caupei*)	74.8	2.3	17.9
Bumper (*Chloroscombrus chrysurus*)		3.1	
Bluefish (*Pomatomidae* sp.)	69.0 – 81.4	2.1 – 4.8	20.4 – 21.6
Philippines			
Alumahan (*Rastrelliger chrysozomus*)	78	1	17
Bambangin (*Lutjanus fulvus*)	70	0.4	20
Tulingan (*Auxis thazard*)	72	1	23
Parang (*Chirocentrus dorab*)	75	1	20
Dapang (*Cynoglossus puncticops*)	80	2	18
Banak (*Mugil vaigiensis*)	73	2.5	20
Bisugo (*Nemipterus taenipterus*)	78	1	18
Sri Lanka			
Goatfish (*Parapeneus malabaricus*)	70.0	1.2	21.0
Trevally (*Caranx* sp.)	77.0	1.5	21.4
Grouper (*Epinephalus undulosus*)	77.0	0.8	16.4
Triggerfish (*Balistes viridescens*)	80.5	2.0	16.1
India			
Carp (*Cirrhina mrigala*)	75.0 – 79.8	0.2 – 4.0	18.1 – 19.6
Mackerel (*Scomberomorus guttatus*)	63.0 – 82.1	0.2 – 14.4	15.9 – 22.4
Lobster (*Panulirus* sp.)	71.5 – 81.2	0.6 – 1.9	16.2 – 21.6
Mackerel (*Rastrelliger* sp.)	73.3 – 79.3	0.5 – 4.1	16.6 – 21.4
Sardine (*Sardinella longiceps*)	75.3 – 76.0	1.9 – 4.6	17.7 – 21.0
Drum (*Sciaenidae* sp.)	69.7 – 80.2	1.0 – 8.4	18.1 – 20.1
Samson crab (*Scylla serrata*)	75.1 – 83.9	0.7 – 4.0	11.8 – 20.1
Carp (*Barbus* sp.)	70.3 – 79.1	2.3 – 3.1	16.0 – 25.2
Japan			
Rockfish (*Sebastes* sp.)	75.1 – 80.0	0.2 – 2.4	17.2 – 20.8
Sandlance (*Ammodytes* sp.)	78.0	1.5	17.9
Pink salmon (*Onchorhynchus gorbuscha*)	69.0 – 78.3	2.0 – 9.4	17.2 – 20.6
Pacific mackerel (*Pneumatophorus japonicus*)	72.3	1.6 – 9.5	21.2
Soles (*Limanda* sp.)	80.0 – 82.7	0.1 – 1.3	17.0 – 19.2
Puffer (*Sphaeroides* sp.)	74.2	0.7	23.2

*Species chosen have been reported of commercial importance in the area indicated.

†Where possible a range of values are quoted but these do not necessarily cover the complete seasonal variations.

Fat (oil)

The fat of true fish is found mainly in the dark muscle just below the skin and in the lateral line area. Some species store fat extensively in their liver, e.g. cod and halibut, others in the head, e.g. halibut, salmon, snappers (*Lutianidae* sp.) and mullets (*Mugil*

sp.), or in the peritoneum, e.g. eels. Many bony fish and sharks and rays have a slightly higher fat content in the belly flap rather than the thicker muscle of the back.

Fat in the muscle consists mainly of triglycerides, i.e. molecules produced from the combination of one molecule of glycerol and three molecules of fatty acids.

$$\begin{array}{l} CH_2-O-CO-R_1 \\ \quad | \\ CH\ -O-CO-R_2 \\ \quad | \\ CH_2-O-CO-R_3 \end{array}$$

R_1, R_2 and R_3 are typically unsaturated fatty acid radicals with between 14 and 22 carbon atoms.

Structure of a typical triglyceride: In fish oils or fats, these fatty acids usually contain an even number of carbon atoms in a long straight chain configuration and include one or more double bonds. The exact nature of the fatty acids seems to be determined partly by what the fish feeds upon (i.e. some fats are taken directly from the feed), and partly on habitat and behaviour (i.e. there are certain differences between marine and freshwater species, and between temperate and tropical species). However, all fish oils are highly perishable and very susceptible to rancidity because of the high content of double bonds.

Triglyceride rich tissues also contain minor components such as the fat-soluble vitamins (A, D and E), fat-soluble pigments (carotenoids, haemoglobin and myoglobin) and cholesterol.

Fat content changes markedly during the year, falling to a minimum when fish are migrating and/or spawning and rising rapidly once feeding recommences. In general, high fat content correlates with high eating quality.

Table 4

Fat content in light muscle, dark muscle and belly flap of some species of fish

Species	Light Muscle fwb*	Dark Muscle fwb*	Belly flap fwb*
Salmon (*Onchorhynchus gorbuscha*)	2.1	12.5	9.5
Haddock (*Gadus aeglefinus*)	0.8	2.0	0.9
Mackerel (*Scomber scombrus*)	18.0	22.0	
Tuna (*Katsuwonus pelamis*)	0.1	0.4	
Crab (*Cancer pagarus*)	0.2	7.5	
Lobster (*Homarus vulgaris*)	0.3	14.5	

*fresh weight basis.

Table 5

Seasonal variation in fat and water contents of mackerel, herring and oil sardine

Month	Mackerel (*Scomber scombrus*)		Herring (*Clupea harengus*)		Oil Sardine (*Sardinella longiceps*)	
	% water	% fat	% water	% fat	% water	% fat
January	57	24			67	13
April	70	9	72	8	77	3
June	74	7	67	13	78	2
July	74	8	59	20	78	3
October	66	14	66	15	66	13
December	57	22			67	13

Protein

Proteins are polymers of amino acids. Three types are found in fish – myofibrillar or contractile proteins (65 – 75 per cent), sarcoplasmic or enzymic proteins (20 – 30 per cent) and stroma or connective tissue proteins (1 – 3 per cent), the last value being much lower than for meat or poultry.

Protein is found in the muscle (16 – 20 per cent), in the skin (approximately 16 per cent) and in the organs. Most figures given in publications are for crude protein and may in some instances be a substantial over-estimate of the true protein content. Protein is normally determined by measuring the nitrogen content of the foodstuff because protein is usually the major nitrogen-containing component. The nitrogen value is usually converted to protein content by multiplying by a factor of 100/16 (6.25) because pure proteins usually contain 16 per cent nitrogen. When this procedure is used, nitrogen in other compounds is also measured and calculated as though it were protein. In many cases, the non-protein nitrogen (NPN) is approximately 10 per cent of the protein nitrogen (PN) and crude protein is a fair estimate of true protein; however, in cartilagenous fish and crustaceans the inclusion of NPN in the calculation may lead to substantial over-estimation.

Table 6

Crude protein and true protein contents of some fish species*

Species	% crude protein	% true protein
Sharks and rays	22 – 29	13 – 19
Pacific sardine (*Sardinella longiceps*)	13 – 20	13 – 20
Pacific hake (*Merluccius productus*)	16 – 19	14.5 – 17
Pacific cod (*Gadus macrocephalus*)	16 – 19	14.5 – 17
Tuna (*Katsuwonus pelamis*)	approx. 25	approx. 18
Crab (*Scylla serrata*)	approx. 19	approx. 14

*Percentage crude protein = percentage total nitrogen x 6.25
Percentage true protein = (percentage total nitrogen – percentage non-protein nitrogen) x 6.25

The protein in fish is of high nutritional value, comparing favourably with other foods of animal origin and generally superior to proteins of plant origin. Obviously, when estimating the amount of protein supplied to the diet by fish, it is necessary to know or estimate the true protein content.

Table 7

Relative dietary value of various proteins

Foodstuff	Net protein utilisation (by children)*
Maize	36
Millet	43
Rice	63
Wheat	49
Soya	67
Whole egg	87
Human milk	94
Cows milk	81
Dried fish	83
Hypothetical ideal protein	100

*Note that NPU determined on laboratory animals can be higher for some proteins e.g. NPU of maize protein for rats is 52.

The relative protein and water content have a considerable influence on the texture of fresh fish. Typically, protein content falls slightly during the non-feeding period and water content rises, perhaps sufficiently to lower the acceptability of the fish.

Carbohydrates

Fish contain far less carbohydrate than foods of plant origin. The small amounts that are present can be ignored so far as nutritive value is concerned. The major carbohydrate in fish muscle is known as glycogen or animal starch. A typical muscle in a live fish or crustacean may contain between 0.1 and 1.0 per cent. Molluscs have a higher content, typically in the range 1 to 7 per cent. This quantity can vary seasonally and, in any case, declines rapidly during the stress and struggle associated with capture, and *post mortem.* The products include small amounts of glucose, sugar phosphates, pyruvic acid and slightly larger amounts of lactic acid in most species. Some species of molluscs do not produce lactic acid but instead a mixture of alanine, succinic acid and octopine.

Extractives

The term extractives is applied to small (i.e. low molecular mass), water-soluble components, some of which are also mentioned in other sections. These substances rarely exceed some 2 per cent of the fresh weight and many individual compounds are present. The ratios of the individual compounds differ markedly with species and such variations are considered to be largely responsible for differences in flavour. Compounds found in the extractives include:

- Free amino acids;
- Small peptides;
- Glucose and sugar phosphates;
- Trimethylamine oxide and trimethylamine;
- Nucleotides and nucleotide degradation products (e.g. adenosine triphosphate, inosine monophosphate and hypoxanthine);
- Creatine and urea;
- Pyruvic and lactic acids.

Since these compounds are water-soluble, they are easily lost by leaching when fish (especially prawns) are stored in ice or refrigerated seawater. Inevitably, losses cause changes in flavour and these will generally be undesirable.

Vitamins

Vitamins may be sub-divided into two groups depending on whether they are soluble in water or fat. In general, fish compare favourably with other foods of animal origin in terms of the vitamin content. Fatty fish are usually very valuable sources of the fat-soluble vitamins (A, D and E). Some fish livers are so rich in these vitamins that they may be recovered as a by-product; such livers may be toxic because of these very high vitamin contents if eaten in large quantity.

Fish flesh and fish gonads are a useful source of many of the water-soluble vitamins, particularly thiamin and cobalamin (B_{12}), the latter being found only in foods of animal origin. It should be noted that fish do not supply significant amounts of ascorbic acid (vitamin C).

Table 8

Typical values for the fat-soluble vitamin contents of some fish tissues

Species and tissue	Vitamin A µg/g	Vitamin D µg/g
Cod flesh	0 – 15	0
Cod liver	60 – 3 000	0.5 – 7.5
Halibut flesh	120	1
Halibut liver	840 – 120 000	14 – 500
Eel flesh	100 – 1 500	0 – 12.5

Table 9

Typical values for water-soluble vitamin contents of some fish tissues

Species and tissue	Thiamin μg/g	Riboflavin μg/g	Niacin μg/g	Cobalamin μg/g
Cod flesh	0.5 – 1.8	0.2 – 1.6	15 – 23	0.002 – 0.011
Cod roe	2.5	5.5	8.0	0.15
Crab flesh		0.9	17 – 28	0.13
Mackerel flesh	0.2 – 2.0	1.6 – 6.6	41 – 114	0.02 – 0.13
Oyster	0.7 – 2.9	0.6 – 3.5	14 – 39	0.15 – 0.46

Minerals

Total mineral, or ash, content of most species falls in the range of 1 to 2 per cent. A wide number of minerals are present in fish flesh, usually in a readily available form. The calcium content of shell and bone is not normally available to the body; however, canning does solubilise it and thus makes available some of the calcium which is present in the bone.

Table 10

Typical values for minerals in fish

Element	Content mg/100g
Sodium	30 – 134
Potassium	19 – 502
Calcium	19 – 881
Magnesium	4 – 452
Phosphorus	68 – 550
Iron	1 – 5.6
Chlorine	3 – 761
Iodine	0 – 2.73

Contaminants

A detailed discussion of the nature and origin of contaminants is beyond the scope of this course. However, in general terms, any compound found in the water in which fish swim or in containers or stores where fish are kept may pass into the flesh. Such substances may come from the feed and cause an off-flavour, in which case little can be done to avoid such tainting. Of more concern, however, is the pick-up of undesirable components arising from pollution. Examples that have received particular attention include methylmercury, radioactive elements and petroleum hydrocarbons.

Naturally-occurring toxins

Some species of fish contain toxic substances which make them unfit for human consumption. A detailed discussion of these substances is beyond the scope of this lecture.

REFERENCES

Physical Structure

1. BORRADAILE, L. A., POTTS, F. A., EASTHAM, L. F. S. and SAUNDERS, J. T. (1959). 'The Invertebrata', Cambridge University Press, 820 pp.

2. COBB, B. F. (1977). Biochemistry and physiology of shrimp. In: *Proceedings of the Conference on the Handling, Processing and Marketing of Tropical Fish,* London, 5–9 July 1976. Tropical Products Institute, London, 511 pp.

3. FRASER, D. I., MANNAN, A. and DYER, W. J. (1961). *Journal of the Fisheries Research Board of Canada,* **18** (6), 893–905.

Chemical Structure

1. GOPAKAMUR, K. (1965). *Indian Journal of Fisheries,* **12B** (1), 1–5.

2. LANTZ, A. W. and GUNASEKERA, C. (1959). *Bulletin of the Fisheries Research Station of Ceylon,* **5**.

3. LOVE, R. M., ROBERTSON, I., LAVETY, J. and SMITH, G. L. (1974). *Comparative Biochemistry and Physiology,* **47B**, 149–161.

4. SIDWELL, V. D., BONNET, J. C. and ZOOK, E. G. (1973). *Marine Fisheries Review,* **35** (12), 16–19.

5. SIDWELL, V. D., FONCANNON, P. R., MOORE, N. S. and BONNET, J. C. (1974). *Marine Fisheries Review,* **36** (3), 21–35.

6. SULIT, J. I., NAVARO, O. B., SAN JUAN, R. C. and CALDITO, E. A. (1953). *Philippine Journal of Fisheries,* **2**, 109–122.

7. WATANABE, K. (1971). *Fisheries Research Bulletin of Zambia,* **5**, 163–173.

Introduction to post-mortem changes in fish and the nature of spoilage

Fish is an extremely perishable foodstuff. Spoilage of fish begins as soon as the fish dies or is caught. In the high ambient temperatures of the tropics, fish will spoil within 12–20 hours depending on species, method of capture etc. A fish, such as cod, from colder waters would spoil in less than 2 days if kept at 20°C but, at a temperature of about 5°C, could remain acceptable for about 5–6 days. Spoilage is the result of a series of complicated changes brought about in the dead fish mainly by enzymes and bacteria. Before we consider how these bacteria and enzymes perform and how they may be controlled, let us look very briefly at what is happening in the living animal.

During life the tissues of a fish, in common with all living creatures, are in a continual state of change. Food is taken into the gut, broken down into small units and transported by the blood to sites in the body where it is required to build up new tissues for growth, for replacement of worn out tissues or to meet the demands of the reproductive system. Simultaneously some compounds are converted to energy and those which are no longer required are broken down in the tissues. As a result of these changes, during life there is always a pool of small units which are easily mobilised for any of the body's requirements. The compounds responsible for these changes are called enzymes. Enzymes are biological catalysts belonging to the class of compounds called proteins and are able to change substances without themselves being changed. They are not themselves 'alive' and so are able to carry on working after the animal has been killed. This process, where post-mortem changes take place due to the action of intrinsic enzymes, is called autolysis (self-digestion).

Bacteria are the smallest free living organisms known. Although they are so small (over a million would fit on a pin head), they perform an essential roll in the natural life cycle on earth. They are found practically everywhere in nature; they can grow and reproduce and can break down complex substances into simple units. Without bacteria, the natural decay of plant and animal material could not take place. Bacteria are found in large numbers on the surface, on the gills and in the alimentary canal of live fish. The natural defence mechanisms of the fish, however, prevent the ingress of bacteria into the fish tissues during life. They feed, grow and multiply outside the fish tissues which in live and healthy fish are sterile. The changes brought about by bacteria occur in exactly the same way as those of autolysis, except that they are caused by the enzymes of the bacterium.

WHY FISH SPOIL

Immediately the fish dies, certain irreversible changes begin to take place. Within a few hours or more the muscles gradually harden along the fish until it is quite stiff. The fish can remain rigid for a number of hours or a few days depending on various factors. The muscles then soften or become pliable again. This stiffening is known as *rigor mortis* and is brought about by enzymes in the muscle. The enzymes of the flesh also cause a complicated series of breakdowns of other tissue components, a

process known as autolysis. In addition, bacteria and, in the case of ungutted fish, digestive juices, can invade the flesh to start the process of putrefaction. Lastly, fat is attacked by oxygen and can give rise to rancidity.

AUTOLYTIC SPOILAGE

At death, the supply of food ceases and the energy resources soon become depleted. The enzymes do not die; they continue to operate but, since energy is required to build the larger units of the body, the function which the enzymes perform *post mortem* is to break compounds into smaller units. This breakdown of tissues affects the flavour, texture and sometimes the appearance of the fish.

Flavour

The characteristic sweet, meaty flavour of fresh fish is due at least in part to a compound called inosinic acid. The breakdown of inosinic acid through autolysis results in a loss of this sweet meaty flavour. Another compound, hypoxanthine, which is produced from the breakdown of inosinic acid, contributes to the bitter flavour of spoiled fish. Autolysis also contributes indirectly to fish flavours by providing a supply of compounds which bacteria in turn convert to compounds having unpleasant flavours and odours.

Texture

The stiffening of fish (*rigor mortis*) and the subsequent softening are caused by autolysis. *Rigor* is of great significance in fish processing, particularly in freezing operations with very fresh fish, i.e. freezing at sea. In *rigor* the fish can stiffen into distorted shapes and they can be difficult to load between freezer plates. Forcibly straightening the fish can lead to serious textural damage in the flesh when filleted. Fillets, cut before *rigor* and then frozen, can contract during storage giving a tough rubbery texture.

Appearance

Some of the discolorations commonly found in frozen fish are probably attributable to autolytic action, in that sugars produced by enzymic action can interact with amino compounds already present in the flesh to produce brownish or yellowish-coloured compounds.

BACTERIAL SPOILAGE

When the fish dies, bacteria present on the surface and in the guts multiply rapidly and invade the flesh which provides an ideal medium for growth and multiplication. The bacteria can break down the muscle itself and will also feed on the smaller units produced by autolytic action. The increase in number of bacteria results in a heavy slime on the skin and gills and an unpleasant ammoniacal, sour odour; eventually they cause the flesh to soften. In addition the gut wall may burst.

The bacterial load present on the fish when caught will continue to multiply until the fish are consumed. However, during handling, they are likely to pick up more bacteria, from being washed in polluted water, careless gutting, dirty boxes etc. However careful one is when handling the fish, there will always be bacteria present but, with care, the numbers can be controlled.

It was noted earlier that the flesh of a healthy, live fish is sterile. From experiments it has been shown that, if blocks of muscle are removed aseptically and maintained under sterile conditions at 0°C for up to 6 weeks, there are no serious organoleptic changes, i.e., no spoilage. Since autolytic changes will of course still be occurring during this period, this implies that bacteria are the main cause of fish spoilage.

OXIDATION OF FAT

In fatty fish, chemical changes involving oxygen from the air and the fat of the fish may produce rancid odours and flavours. The problem is of importance, particularly when storing frozen fish for fairly long periods. Glazing before cold storage and adequate packaging helps to alleviate the problem. Fat oxidation can also be a problem with smoked and dried fish.

Preservation and processing: broad aims

We have talked about the mechanisms which occur in fish flesh after death and which produce changes making the fish either unacceptable to the consumer or unfit for consumption. We will now look briefly at some of the ways in which the mechanisms which cause spoilage are slowed down or stopped. Broadly, there are two main areas: those of preservation and those of processing. Preservation methods are those that endeavour to keep the fish in a fresh state so that the changes in texture, taste, appearance etc. are minimised. Processing methods usually change the texture, taste, physical appearance etc. of the fish so that deterioration is slowed or halted but the fish has changed characteristics associated with the process used. In general, two different species of fish processed in a similar manner are more alike than the fresh and processed product from the same species.

PRESERVATION METHODS

Bacterial and autolytic spoilage are biological systems which operate only under certain optimum conditions. Thus, altering the conditions can provide ways of preventing or reducing spoilage. Since bacteria require water and are sensitive to heat, salt concentration and pH, there are a number of approaches which can be used. Control of autolysis is, by definition, control of enzyme activity. By far the most common and practicable way of reducing autolytic action is by lowering the temperature but enzymes can also be inactivated by other means, e.g. irradiation or with chemicals.

Temperature control

The bacterial flora of fish and the enzymes present in the tissues are adapted to the temperature at which the fish lives. i.e. around 5–10°C for fish from cold waters and 25–30°C for tropical fish. By lowering or raising the temperature, bacterial and autolytic spoilage rates will be reduced.

In broad terms it can be said that the lower the temperature, the slower the bacterial and enzyme activity and, consequently, the longer the storage life. Thus fish can be chilled or frozen.

Chilling: This is holding fish just above (or at) their freezing point. In tropical climates this would mean that the temperature of the fish would be reduced from say 25 to 1°C. Ice is an ideal medium for chilling; more and more fisheries are now using ice to chill the catch. Ideally, fish should be chilled as soon as possible, whether they are to be used fresh, frozen, dried etc. Storage in ice is a short-term method although some species can be stored for up to one month.

Freezing: This is for longer-term storage. The much longer shelf life of many months to a year is due to the following:

1. Autolytic and bacterial action are almost completely halted at the recommended frozen storage temperature of –30°C.
2. Water is effectively removed by being locked away as ice.

Whilst the long shelf life of frozen fish is to be desired in a number of situations (particularly for high value products which are to be exported or for storing excess amounts of fish in a seasonal fishery), in many others a freezing operation is totally unnecessary. Furthermore, the plant needed for freezing and frozen storage of fish is generally very expensive to buy and costly to run.

Use of radiation

Another method of preservation of fish which has not been used widely is by the use of ionising radiation. Radiation in suitable doses is capable of killing micro-organisms, insects and parasites which may be present in food and also inhibiting the action of enzymes. Due to the expense involved, irradiation is not used commercially to any great extent.

PROCESSING METHODS

Raising the temperature

Generally, raising the temperature involves the cooking of fish, for example, in canning, boiling and smoking.

Canning: The fish are subjected to high temperatures to kill the bacteria and inactivate enzymes. Once the bacteria and enzymes are inactivated, the product must be protected from further bacterial contamination by being hermetically sealed within the can. The inside of the can must be resistant to its contents and the outside resistant to ambient conditions. Canned fish will keep for long periods but canning is often an expensive process. Canning operations are generally successful only on a large commercial scale for species such as tuna, sardines etc.

Boiling: Fish can be boiled with or without salt and the shelf life can then be extended by a few days under tropical conditions. Boiled fish is popular in South East Asia. In some places the fish are dried after boiling to give a longer shell life.

Removal of moisture

The moisture content of fish in the fresh state is about 80 per cent; if this is reduced to around 25 per cent, bacteria cannot survive and autolytic activity will be greatly reduced. At moisture contents of 15 per cent or less, moulds will cease to grow; well dried fish, if stored under the right conditions, can be kept for several months. Drying can be carried out alone or in combination with smoking or salting. Whether the fish are dried, smoked dried or salted and dried, the aim is to remove moisture as quickly as possible, before spoilage occurs.

Natural drying: Fish can be dried in the sun by using the sun's energy to drive the moisture out. If they are very small they can be left whole, otherwise they should be split to increase the surface area. Sun drying has a number of disadvantages but the main advantage is that the energy is free. The sun's energy is also used in solar driers and black box drying but these systems are usually only used experimentally.

In colder climates, e.g. Iceland and Norway, wind is the main agent that dries the fish. Since the air temperatures are very low, spoilage is slowed down. The fish are headed and gutted (and split if large) and hung in the open air for about 6 weeks until hard and dry. This type of product is called stockfish.

Mechanical drying: Traditional drying by sun and wind is slow and at the mercy of the weather. With mechanical drying it is possible to control the temperature, humidity and air flow but fuel, e.g. electricity or oil, which is very expensive in many countries, is required to run the heaters and the fans.

Smoking: In many tropical areas fish are smoked over open fires or in simple kilns in order to accelerate the drying process. If the relative humidity is high and salt is scarce (as is often the case in many African countries), hot smoking, where the fish is cooked (and often charred), is the only method of preserving fish. Wood or some other locally available combustible product is used.

Cold smoked products, in which the flesh is not cooked, are enjoyed in many developed areas of the world. Smoking is carried out as a means of giving a desired flavour *rather* than as a method of preservation. Refrigeration is necessary in order to keep such products for long periods. Cold smoking is rarely carried out in the tropics.

Throughout the world, many different types of fish are smoked by a large variety of smoking methods. These range from traditional processes in which the fish are smoked over open fires or in simple smoking ovens to improved processes using vertical kilns and, particularly in developed countries, using sophisticated mechanical kilns.

Salting: Salt is often used in conjunction with drying and smoking. If salt is rubbed into the flesh of the fish or the fish are placed in brine, water is removed and salt passes into the flesh. As most bacteria cannot grow in salt concentrations above 6 per cent, salting will, therefore, reduce bacterial action. There are, however, groups of bacteria that like a salty environment, i.e. halophiles, and these can cause problems in salted fish.

Fish sauces and pastes

Fish sauces and pastes are very popular in South East Asia being produced, in the main, by adding fish and salt together and allowing them to ferment. The result is either a paste or a liquid separated from the fish solids, which is used for condiment purposes. The particular pastes and sauces made from different types of fish and shrimp have their own characteristic flavours and odours.

Fish processing: the broad aims and socio-economic aspects

In most of the sessions of this course we are concerned with the scientific and technical aspects of fish as food. In this lecture we shall examine some of the ways in which people may be affected by the way fish are processed and subsequently marketed.

THE PROFIT MOTIVE

No-one goes fishing for fish alone; people fish to make money and fish processors are in business to make a profit.

A particular processing method may be chosen because it is the most profitable of the options open. Sometimes, of course, there is only one option, e.g., on many isolated coasts fishermen can only sell their catch if they cure it by salting and sun drying or if they make a fermented product. In other cases there may be a choice between selling the fish fresh, (usually chilled), freezing it, or making a canned product.

Two other aspects must be considered. Firstly, fish are an extremely perishable commodity and everyone involved in a marketing chain must aim to move the fish along before they deteriorate. Thus, there is pressure to dispose of them as soon as possible. Alternatively, fish which have been subjected to some kind of processing can, however, be sold for a *higher price* than raw fresh fish. There is, therefore, a pressure to add as much value as possible to the catch by, for example, canning it in the country in which it is caught, rather than exporting frozen fish which will eventually be canned in a distant country.

Secondly, it is not always practicable to carry out technically advanced processing operations such as canning in a developing country. For one thing, the size of the local catch may not justify the erection of a processing line; also thermal processing operations are very capital- and energy-intensive. Machinery may well have to be imported and this may mean that it is cheaper to move the fish to a plant than to erect a plant where the fish are caught. The end product has to be sold and this may be extremely difficult for a new processor without a built-up reputation.

FINANCING FISHING AND FISH PROCESSING OPERATIONS

It is impossible to completely separate fish catching from the fish handling and processing operations. In much of Asia, fishing and fish marketing operations have traditionally been financed by trader-financiers. The same is true in much of Africa. Lawson summarises the experience of many countries in attempting to devise systems which would improve the income of the small-scale fisherman.

It was at first thought that the obvious way to do this would be to introduce new and improved boats, gear and equipment but it was soon found that this could only

be administered by a suitably trained Fisheries Department or Extension Service. In order to enable fishermen to own their own gear and vessels, many Governments were obliged to devise some scheme for providing fishermen with adequate credit and loan capital. Some of the countries which pioneered loans schemes, however, soon found that their ability to recover debt repayments was frustrated by what was considered to be the control exercised on the industry by traditional fish traders, many of whom also provided capital to the industry and thus performed, simultaneously, a trading-financing function.

Relationship between fishermen and trader-financiers

As a result of this, the package of inputs applied to develop the small-scale fisheries was enlarged to include the introduction of what were thought to be improvements to the marketing network. These improvements aimed at reducing the power of the trader and giving the fisherman a greater share of the profits of the catch. It was assumed that, given such an opportunity, fisherman would work harder to increase their levels of income and hopefully to use some of it to invest in their own vessels. Field research suggests that much of this attack on trader-financiers is based on a misunderstanding of the wide array of functions which they perform and an exaggeration of their power. It is true that, under certain conditions, various degrees of monopoly or oligarchy do exist but these are not necessarily exploitative or always resented by the fishermen and, in general, fishermen and trader-financiers often have a mutually beneficial relationship which operates smoothly in a traditional environment. Any interference with this *status quo* is bound to be resented by all parties. Lawson notes that an instance of this was provided in Ghana when it first attempted to introduce mechanised fishing vessels in the mid-1950's. This was effectively resisted by both canoe fishermen and traders who combined forces on the beach to prevent fish from mechanised vessels being landed.

In addition to attempting to provide credit to small scale fisheries, many countries have attempted to introduce wholesale markets or auction markets for the fish trade. In many cases, these attempts have met with no success whatsoever. Unless there are obvious benefits to the fish trader as well as to the fisherman, it is unlikely that the traditional fish marketing system will be replaced due to the threat of action from both fishermen and traders. In fact, in many developing countries, there are large government-built wholesale markets which are little used. An understanding of the socio-economic functions of the traders in the traditional fisheries sectors would have indicated beforehand that this would be a likely result.

It has often been a basic assumption that small-scale fishermen are tied in a spiralling debt situation with the trader-financiers who perform the essential credit and marketing functions. In all developed, as well as undeveloped countries, the trader and middlemen tend to be the focus of political attacks. In most countries, the trader is seen as adding nothing to the real value of the product, he is considered to be a parasite. A little thought shows that the real value of his trading functions lies in the fact that he takes the risks, acts as a collector, assembler, organiser and redistributor. While the trader-financier is often the owner of the vessels, gear and other equipment used by fishermen, it should not be assumed, without an examination of the socio-economic functions performed under this traditional system of ownership, that the trader-financier is using this as a means of exploiting the fisherman, or even that the small-scale fishermen really want to become equipment and vessel owners themselves. In Malaysia, for example, recent studies of the commericial activities in the small-scale fisheries have shown that the return on boat ownership is between 10—15 per cent/annum only. This is probably well below the opportunity cost of capital in all developing countries, which is usually at least 20—25 per cent at free market prices. The trader-financier is in a different position from the fisherman — he hopes to earn profit from his combined activities of financier and fish trader so that in aggregate he gets a reasonable return on his capital as well as an adequate reward for his time, effort and enterprise and risk-bearing function.

It seems likely that, like the other low-income rural producers, the small-scale fisherman's greatest need is to have a guaranteed minimum subsistence level of income. It may well be that the price paid by the fishermen for a confident level of subsistence is their willingness to enter into a perpetual debt relationship with the financier. The fishermen's needs are often few. Many of them do not know what they would do with extra cash if they were able to acquire it.

Most fishing is seasonal and fishermen may therefore find themselves forced to borrow for consumption purposes at times when fishing is poor. The incidence of debt is highly seasonal and much credit may be given by shopkeepers and general traders not intimately connected with the fishing industry. The need for short-term finance, which is small in amount and frequently needs to be given quickly, is characteristic of all societies where production is small-scale and highly seasonal and where no alternative source of income is available. Since most borrowing is undertaken within the traditional sector itself and is based on mutual trust and respect between members of a community, there are few bad debts. Debt collection is cheap and those responsible for giving credit or making loans generally know exactly how much they can safely give. Many attempts to replace this system with institutional lending have proved to be costly, risky and cumbersome. Many attempts were also bogged down by bureaucracy and it is not always easy to see exactly why they have failed. It can work the other way too — fishermen sometimes extend credit to traders, especially where coastal traders must sell on credit to inland dealers.

Fisheries co-operatives: an alternative to the traditional system

The best alternative to the traditional system would seem to be in the establishment of fisheries co-operatives or fishermen's associations. The earlier attempts to establish these in developing countries proved extremely expensive and totally unproductive. Fishermen are independent individuals and it is perhaps not too surprising that they do not necessarily readily co-operate one with another. The possible advantages of co-operation are very obvious to the outsider; these include such things as reduced costs obtained by purchasing supplies in bulk and collaborative arrangements for the transport and marketing of fish. The answer seems to lie in improved education; where fishermen have the advantages of a good education, they can see the advantages of co-operation. There are now very successful fisheries co-operatives in many countries, including a small number of developing countries. The advantages extend across the whole spectrum of fish catching, handling and processing operations, including technically advanced processing operations.

Co-operation is not necessarily the only route to success; in the Western countries, co-operative societies often flourish alongside businesses operated by individual entrepreneurs. There is a place for both.

THE ECONOMICS OF PROCESSING

Costs and prices are at the present time so variable that there is little point in attempting to give actual figures here for processing costs. Instead an attempt will be made to provide some indicative parameters. These parameters are based largely upon the cost of plant and equipment purchased in a developed country and then frieghted to and operated in a developing country. The figures present only an order of magnitude and should only be used as such. Obviously, wherever a new plant is desired, an individual study should be made and costings prepared.

The profitability of an enterprise is represented by the revenue less the total costs of the operation. The costs are represented by three separate elements:

(a) The *capital costs*, which are necessary to establish the enterprise in the first place. These include the purchase of buildings, plant and equipment; design and installation charges; taxes; fees; freight and insurance charges.

(b) The *annual fixed costs.* These include the annuity value of the initial capital investment and all the other charges which do not vary with the level of the operation and must be paid whether the plant is working or not. The most important of these are rent, maintenance costs, insurance, taxes and management expenses.

(c) Finally there are the *operating costs;* the principal variable costs are the prices paid for raw material, labour, utilities (fuel, electricity and water) and packaging.

Capital costs

Building costs: These are a major item, especially if difficulties are encountered in obtaining essential supplies such as steel or cement. Building costs vary widely according to material and specifications but, as a general guideline, building costs of between US $100 and 150 per square metre are currently about average. Where conditions are difficult a higher figure may be needed.

The size of building needed increases with the capacity of the plant but not in a linear manner since the actual plant takes up a relatively small proportion of the total area. The remainder is taken up by storage space for raw materials and end products, ancillary activities such as preparation and packaging, and office space. In terms of building area a small to medium plant and ancillary activities may occupy only 200–300 m^2 but the whole operation may need a site from 500–800 m^2, the additional space being needed mainly for storage.

Different sorts of processes have very different requirements: a fish reduction plant manufacturing fish meal needs relatively little space since no hand-operations are involved; a cannery, however, needs relatively much more space for the same throughput of fish because there are inevitably a number of hand-operations. Much depends, of course, on the degree of mechanisation within the plant. Whilst it might be possible to get a fishmeal plant handling 20 to 30 tonnes of raw fish a day into a space of 500 m^2, at least 800 m^2 would be needed for a very small cannery. Increasing the plant capacity for fish meal has a relatively slight effect upon overall space requirements but a medium-sized cannery handling 20 to 30 tonnes of raw fish a day would need at least 2 000 m^2 floor space. Relatively simple buildings are needed for fishmeal manufacture and a fishmeal plant dealing with 100 tonnes of raw material per 8-hour day could well be accommodated within a total building cost of around US $100 000. Canning and freezing facilities are more demanding and similar throughputs could well cost more than twice as much. It is interesting to consider the general level of building costs in relation to throughtput.

Table 1 indicates the general level of building costs in relation to throughput and their annual costs on the basis of a 20-year life at 12 per cent interest and consequently the order of magnitude per tonne of raw material processed.

Table 1

Building costs per tonne of raw material

Capacity tonnes of raw material per day	Total building cost US $ x 10^3	Annual equivalent US $ x 10^3	Cost per tonne of capacity* US $
1–5	30–60	4–8	18–7
6–20	40–90	5–12	4–3
21–50	65–190	9–25	2
51–100	100–240	13–32	1

*Number of working days = 225

It is readily apparent that the small plant, if housed in a building of generally accepted standards, is at a considerable disadvantage in relation to larger plant capacities if it has to bear the full cost of building. It is, therefore, a considerable advantage if developing countries can obtain concessionary terms for such investment, particularly when it is remembered that the market open to a young industry often needs developing and that, therefore, a relatively small initial plant capacity may be appropriate.

The plant and equipment costs: This is generally the most expensive single item of expenditure. While precise costs depend very much on plant size and the degree of mechanisation, the underlying assumption made here is that operations remain as labour-intensive as possible. The smallest fishmeal line processing about 2 tonnes of raw material in an 8-hour shift now costs in the region of US $200 000 which rises to around US $800 000 for a plant processing 20 tonnes in an 8-hour shift; an amount in excess of U$ S2 000 000 might be needed for a plant handling 200 tonnes in a shift. It is, of course, normal practice to operate a fishmeal process throughout the 24 hours where this is possible.

The minimum investment for a canning plant handling a throughput of 2 tonnes of raw material a day is of the order of US $340 000, this rises to US $600 000 for a plant handling 10 tonnes of raw material a day and then to US $1 000 000 for a plant handling 30 tonnes per day. A 30 tonnes per day cannery is a relatively small one.

It is particularly difficult to be precise about freezing plant throughputs since much depends upon the product involved and the amount of processing it undergoes before and after freezing. Throughputs are generally related to the capacity of the freezing unit which might vary from one fifth of a tonne to 50 tonnes per day. The cost of freezing units is relatively small but the actual freezer represents only a small proportion of the plant cost. The smallest freezing unit now costs about US $20 000 and the largest about US $500 000. Ancillary equipment and storage facilities for a plant freezing 1–2 tonnes of raw material a day probably puts the minimum plant and equipment cost in the region of US $80 000 rising to US $200 000 for a freezing plant handling 5–8 tonnes of raw material a day. Table 2 shows calculations similar to those given for building costs. Plant and equipment costs for varying throughputs of raw material are given and reduced to an annual rate of repayment, assuming a 10-year useful life and an interest rate of 12 per cent.

Table 2

Plant and equipment costs per tonne of raw material

Capacity tonnes of raw material/day	Total plant cost US $ × 10^3	Annual equivalent US $ × 10^3	Annual throughput in 25 days tonnes	Cost per tonne of raw material US $
1–5	60–170	11–30	225–1 125	49–27
6–20	160–140	28–71	1 350–4 500	21–16
21–50	230–500	41–103	4 725–11 250	9
51–100	370–780	65–138	11 475–22 500	6

There are additional costs to the building and plant costs ex-works; allowance has to be made for costs incurred up to the time the plant is commissioned. Most obvious items are the erection and installation costs, freight and insurance. As a general rule of thumb these charges, including pre-production trials and an allowance for spare parts and supervision fees, may be calculated at 10–12 per cent of the capital cost.

Freight and insurance charges can vary widely depending on volume, weight and destination of the goods transported but for illustrative purposes a conservative figure of 20 per cent of the value of the goods may be used. Taxes and duties obviously vary greatly and can be severe on certain items of equipment. Conces-

sions are sometimes given for items provided within official aid programmes. It is usual to include a contingency sum of 10 per cent of the estimated capital cost in any provision budget.

Table 3 summarises the capital cost involved on an annual equivalent basis in establishing fish processing facilities. The relationship of capital cost to plant throughput is self-evident. It is an important relationship and there are obvious attractions to entrepreneurs in opting for a medium-sized plant with a throughput of, say, 25–30 tonnes of raw material per day. There is obviously no point in opting for a plant of this size unless this quantity of raw material is available. This is one of the major problems in attempting to associate a processing plant with a small-scale fishery.

Table 3

Indicative capital costs of fish processing plants (annual equivalent basis)

Capacity tonnes of raw material/day	Building costs US \$ x 10^3	Plant costs US \$ x 10^3	Miscellaneous* US \$ x 10^3	Total costs US \$ x 10^3	Cost per tonne of raw material US \$	Cost per tonne of raw material at two thirds capacity US \$
1–5	4–8	11–30	6–14	21–52	93–45	140–69
6–20	5–12	28–71	12–30	45–113	33–25	50–38
21–50	9–25	41–103	18–47	68–175	14–16	21–14
51–100	13–32	65–138	29–62	107–232	9–10	14–15

*Calculated at 10 per cent site costs, 10 per cent contingency allowance and 20 per cent freight/insurance but no allowance for taxes or duties

Not only is lack of raw material to be feared; the demand for the product needs to be considered very carefully. The result of over estimating demand or supply and perhaps having to run a plant at only two thirds of its capacity is well illustrated by Table 3. A plant with a capacity, for example, of 20 tonnes a day running at only two thirds capacity has higher overheads than a 6 tonnes per day plant running at full capacity. Similarly a 51–100 tonne per day plant running at two thirds capacity has much the same overhead costs as a 21–50 tonne per day plant at full capacity.

Annual fixed costs

Several other items of a fixed nature, which do not vary with the level of operation but which must be paid whether the plant is working or not, must be included. The most important of these are rent, maintenance costs, insurance, taxes and management expenses. For the purpose of establishing guide lines, insurance and maintenance costs can again be based upon a percentage of the plant's value; 2 per cent for the former and 5 per cent for the latter. Rental value used is most likely to be the annual cost of a lease on the land but in some cases land is, of course, provided at a very cheap rate for a new development. The tax position is so variable in different countries that it is difficult to comment. New enterprises are often given a tax holiday of up to 5 years. Conventionally, management costs are considered to be annual fixed costs although this often gives rise to questions of definition and inactive plants would not necessarily incur management costs. Normally, even the

Table 4

Annual fixed costs of fish processing plants

Tonnes of raw material/day	Total annual fixed costs US \$ x 10^3	Processing capacity tonnes of raw material	Cost per tonne US \$
1–5	33–40	222–1 125	147–36
6–20	40–70	1 350–4 500	30–16
21–50	64–105	4 725–11 250	14–9
51–100	99–140	11 475–22 500	9–6

smallest plant should budget costs for management of about US $20 000/annum. For larger plants, the allowance should be nearer US $50 000. Finally, the enterprise is likely to need working capital of the order of 3 months' production cost on which interest will also be paid. The sum total of these costs in relationship to the daily processing capacity is shown in Table 4.

Taken together, the annual fixed costs plus the annual repayment charges (Table 3) can amount in the case of the smallest plants to a cost of the order of US $250 per tonne of raw material. The range of estimates given in Table 4 is very wide but it can be seen that the small capacity plants carry enormous costs. Here again a medium-sized plant dealing with 20–30 tonnes of raw material per day appears to be a more attractive investment than either a very small or a very large plant.

Operating costs

Cost of raw material: This is crucial to any processing operation because it is usually the primary cost element per unit of capacity and is the one subject to greatest fluctuations. There is little point in attempting to discuss actual costs since these are so variable, beyond noting that raw material for both canning and fish-meal manufacture must be extremely cheap if the product is to compete on the world market. The cost of utilities is similarly very variable and there is little point in attempting to comment on the cost of electricity or fuel oil since these vary so much from place to place.

It is, however, worth noting that water is an integral part of any freezing plant process, being needed for boilers, cleaning, cooling and staff facilities. A clean ample water supply is of vital importance and some plants may have to be faced with the cost of installing their own supply from a bore hole. Even a relatively small plant processing only 2 tonnes of raw material a day should use upwards of 3 000 000 gallons annually or about 290 m^3 per tonne of raw material. A small cannery is likely to need 150 m^3 per tonne of raw material while a reduction plant uses only a quarter of this amount.

Labour: This is obviously another important operational cost. There must be both administrative and clerical staff, and production workers. In large plants, production and marketing will be separate functions while in the smaller plants the same man may look after production and sales and the plant owner may well do most of his own book-keeping with minimal clerical assistance. The smaller plants, again, seldom have quality control laboratories which enable them to check the quality both of the incoming raw material and of the final products. This is one of the reasons why it is difficult for small plants to establish themselves as exporters of fishery products.

The quantity of labour needed for the production line depends very greatly upon the degree to which the plant is mechanised. For social reasons, it may often be desirable to provide as much employment as possible. Unfortunately, the work provided is often more suitable to the capabilities of young inexperienced staff than to the heads of families, so that it is sometimes a fallacy to assume that a fish processing plant will have much useful impact upon an unfavourable employment situation. Most machinery can be relatively easily cleaned, people carry germs and it is not always easy to supervise personal habits of staff. Importing countries which have themselves high standards of hygiene will not tolerate the import of dirty food.

Machines are not often only quicker but also more reliable than people. Looking at some simple examples and taking gutting as the first operation, a skilled man can cut about 200 to 240 cod, each weighing about 3 kg, in an hour. The same man would gut 300 small codling an hour but only 150 large cod. A machine can gut 25–40 fish a minute; three men can mind 2 machines so that they can do the work of 10 to 12 men.

The position is more complex when one considers filleting. A skilled hand filleter dealing with 3½ kg cod can remove the fillets from 60–70 fish an hour and will obtain a yield of 25 per cent. A machine might handle 40 fish per minute or 2 400 an hour but give a yield of 41–45 per cent with an average of perhaps 43 per cent. Even where wages are very low, it might well pay to use a machine rather than employ people to fillet by hand. Again much depends on the value of fish in terms of the differential yields. For some work, a machine would be regarded as essential; in Europe it would be too slow an operation to fillet herring by hand and a machine will fillet from 190–280 fish per minute, depending on their size and certain other factors, if it is fed by four people. In America, it is considered that a skilled worker can produce from 2½ to 3 kg of peeled shrimp an hour. One machine can do the work of 16 workers. A few machines can make a vast difference to the speed at which a cannery operates but, even so, many processes still require hand-filling of the cans.

Fishmeal plants are relatively capital-intensive and a plant processing up to 20 tonnes of fish a shift would probably employ only four or five men while plants processing 200 tonnes a shift would make do with as few as 15 people. A labour-intensive cannery, on the other hand, might need 90 production workers when processing only 2 tonnes of raw material a day; 40 of these people would be carrying out tasks which could be done by machine. The number of workers needed in a freezing plant depends entirely on the type of product made; a plant processing 20 tonnes of fish might need 80 production workers, in addition to supervisory and administrative staff, if no machinery were available; less than half that number of people might be employed if the plant were fully mechanised. Plants freezing shrimp would employ several hundred people for the same quantity of raw material.

Total operating costs

There is no doubt that the very *smallest types of plant are at a disadvantage when compared with the larger ones.* It would also seem to be apparent that plants with a throughput of 20–30 tonnes of raw material a day have a certain attraction in that, beyond this size, the benefits of economies in scale are not nearly as dramatic as they are up to this level.

REFERENCES

1. LAWSON, ROWENA, M., (1977). Socio-economic aspects of fisheries development. In: *Proceedings of the Conference on the Handling, Processing and Marketing of Tropical Fish,* London, 5–9 July 1976. Tropical Products Institute, London, 511 pp.
2. SHAW, J. R. (1977). Economics of fish processing. In: *Proceedings of the Conference on the Handling, Processing and Marketing of Tropical Fish,* London, 5–9 July 1976. Tropical Products Institute, London, 511 pp.

Instruments

The Shorter Oxford English Dictionary defines an instrument as a 'thing with, or through, which something is done or effected', 'a means' or 'a tool'. In the fish processing industry many 'instruments' are used which fall outside the scope of this session; for instance, a fish filleting knife is an instrument for cutting fish in a particular way and a grind stone is an instrument for sharpening that same knife. However, here we will be considering some of the pieces of apparatus through which some measure of control is effected on operations in the fishing industry.

These instruments fall into two main categories:

1. Those which control a process directly.
2. Those which indicate to a human observer that a particular condition exists.

Instruments of one sort or another are used by almost every industry and, in some, instrumentation can be extremely expensive. However, many of the instruments used in the fish industry are relatively cheap and their proper use can actually save costs. In many instances, adequate control of the process or product can be achieved only through the use of instruments.

In the fish industry, temperature, time, weight, air flow, pressure and moisture are perhaps the most commonly measured (or controlled) variables. A measuring instrument may indicate the present reading or situation, e.g. a 'spot' reading thermometer, or it may show what has happened over a period of time, e.g. a recording thermometer. A controlling instrument is a measuring instrument with a built-in switch or regulator to keep the conditions within certain specified variables such as a thermostat which controls the temperature of a smoking kiln. Some of the more elaborate and expensive instruments may measure, record and control.

In this session we will look at the basic principles of some of the instruments which can be used in the fish processing industry.

THERMOMETERS

During fish handling, processing, transportation etc., temperature is perhaps the most important factor to measure and control. At high ambient temperatures, fish spoil very rapidly and, therefore, they must be cooled quickly. The correct freezing temperature must be employed for rapid freezing and the temperature of smoking must also be controlled.

During any process the temperature must be checked frequently and, if it has fallen or risen, corrective action must be taken. Also, the device itself must be checked regularly for correct functioning. There are various ways in which the temperature may be measured, different types of thermometers are more suitable for particular sets of circumstances.

Liquid expansion

A familiar example of this type of thermometer is the common clinical mercury-in-glass thermometer. As the temperature rises, the mercury in the bulb expands along the fine capillary tube which is marked in degrees Centigrade (or Fahrenheit). The main disadvantages of liquid-in-glass thermometers are: they are fragile; they are often difficult to read; they must be read *in situ*; the column of mercury can break. They are, however, relatively cheap. Mercury freezes at −39° C and boils at 357° C. Mercury-in-glass thermometers are made to cover a variety of temperature ranges within these limits. For lower temperatures, a different liquid must be used, such as alcohol which has a useful range from −79 to 71° C; a pink dye is usually added to the alcohol.

Another type of liquid expansion thermometer is the mercury-in-steel thermometer. The capillary can be made very long and can be bent around corners; hence it is more suitable for measuring temperatures at a distance from the bulb. The temperature is measured indirectly usually by a Bourdon (pressure) gauge, which can be linked to a pointer moving on a dial or fixed to a pen which traces a record on a moving chart.

The response of liquid expansion thermometers is sluggish and for this reason they are most suitable for measuring 'steady' temperatures, for instance in a cold room. Also, because the bulb is large, and breakable if glass, it cannot be used for inserting into fish etc. Other types of thermometers are used for measuring rapid changes in temperature and for insertion into fish.

Solid expansion

Metals expand when their temperature is raised but the extent to which they expand varies from one metal to another. Some steels containing nickel and chromium hardly expand at all when their temperature is raised over a wide range; other metals such as copper expand considerably. This phenomenon is used in bimetallic strip thermometers and in thermostats. The bimetallic strip consists of two strips of dissimilar metal joined along their length. As the temperature rises, one side of the strip expands more than the other and causes the bimetallic strip to curve; the degree of curvature depends upon the temperature rise.

Electrical resistance

This type of thermometer depends upon changes in electrical resistance in a wire with change in temperature. It measures resistance to the flow of electricity passing along a very fine coil of wire in the sensitive tip.

The advantage of the resistance thermometer is that the tip can be extremely small and the response is very rapid. The sensitive element (thermistor) can be fitted into a variety of different types of probes, i.e., general purpose, heavy duty, surface, hypodermic needles and catheters. The electric circuit, meter and battery necessary for measuring changes in the resistance can be fitted into a small portable box which may be at some distance from the sensitive tip.

Thermocouples

If two wires of different metals are joined in a loop and one junction is heated, a small electric current will flow round the loop; opposite voltages are produced at each junction and this difference between them causes the current to flow. The voltage depends on the metals and the temperature difference between the hot and cold junction. Providing that the voltage produced corresponds regularly to the temperature difference, this system can be used for measuring temperature.

The voltages produced are small and, hence, the measuring device must be extremely sensitive. This can be a voltmeter in the circuit which measures the thermocouple voltage or another voltage, from a battery, may be fed into the circuit to oppose the thermocouple voltage. Measurement of the voltage that is required to stop the current flowing gives a more accurate measure of the thermocouple voltage but

sometimes the direct method, using a voltmeter, is preferred. The apparatus for measuring the electrical output may be complicated and expensive.

In many of these types of thermometers, the readings are recorded on a chart; others may be adapted to switch heaters on or off as in thermostats. Thus thermocouples are used mainly to measure temperature but also, in some cases, to control temperatures. The advantages of thermocouples are that the response is rapid; the junction can be even smaller than the thermistor; the thermocouples themselves are generally cheap.

BALANCES AND SCALES

Balances or scales are used frequently in the fishing industry; for example, fish are sold by weight; weight losses are monitored during freezing and storage; fish are weighed before and after drying to establish the percentage moisture. Although many different types of balances and scales are available, they are based either on the spring or beam principle.

Spring balances

The object to be weighed is attached by a hook, bucket or pan to one end of the spring; the other end is fixed to the main body of the balance. As the spring extends, a pointer moves and the weight is indicated on a scale. Spring balances are simple and robust and give a rapid reading. However, they are not always very accurate and, in time, the spring may distort.

Beam balances

The simplest type of beam balance is in effect a see-saw with a pan at each end. The object is placed on one pan and known weights are added to the other until the beam is horizontal. The 'beam' principle is used in many different types of balances, for example, the steelyard, platform scales and a number of direct-reading pan balances which are used in shops, markets, factories etc. Beam balances used in the fish industry are generally very accurate, reliable and robust. Often the balance will have a 'tare' facility.

TIMERS

Timing is important in a number of fish processing operations, particularly for freezing and brining. A variety of simple, robust timers is available. These may be clockwork, electric or electronic; some have a bell or buzzer incorporated which can be set to sound after the required period of time; others may switch on a warning light; while others can switch off the equipment at the end of the process or change from one part of a process to the next. An approximate idea of time can also be important, e.g., length of time before fish are iced, time taken to load and unload freezers, delays during processing etc.

PRESSURE GAUGES

Pressure gauges are used for direct measurement of pressure, although this is usually the pressure difference between, say, the steam in the boiler or retort and the air outside, and for indirect measurement of temperature and the flow of liquids or gases.

The simplest and cheapest type is a U-tube which is filled with a suitable liquid, i.e., one which does not evaporate quickly, such as mercury or a light oil. Pressure-measuring instruments with a pointer which moves on a dial are preferred. Many of these operate on the Bourdon tube principle. The Bourdon tube is essentially an oval shaped or flattened tube which may be C-shaped or a flat spiral. As the pressure increases inside the tube, it tends to become less flattened and tends to straighten;

the degree of 'straightening' depends directly on the pressure. One end of the tube is fixed and the other is attached, via gears and levers, to a pointer on the dial. Care must be taken when using the Bourdon gauge not to exceed the stated pressure as the walls of the tube are extremely thin and the gears and levers are easily damaged.

Bourdon tubes are widely used. Their use in conjunction with the mercury-in-steel thermometer has already been mentioned. They can register pressures below and/or above atmospheric. A specially designed gauge with a spike which, when stuck into a can makes an air-tight seal, is used for measuring pressures inside the can.

HYDROMETERS

Hydrometers measure the density of liquids. Density is the weight of a known volume of a substance and is often related to the density of water: 1 cubic centimeter of water weighs 1 gram; 1 cubic centimeter of benzene weighs 0.8724 grams. This relative density is called specific gravity; the specific gravity of benzene is 0.8724.

Although hydrometers measure density, usually what is of more interest is the information which they give about what is in the liquid. A special type of hydrometer called a brineometer or salinometer is used to find out how much salt is in a brine solution. Brineometers are marked in degrees; these may be salinometer degrees (a saturated solution is 100°, pure water is 0°), Baumé degrees or Twaddell degrees (see Table 1). Thus, a saturated brine solution (at 16°C) contains about 360 g per litre and an 80° brine, which is commonly used in fish smoking, contains 270 g per litre. For practical purposes, the errors in using salinometers at higher temperatures are comparatively small and can be neglected.

Table 1

Brine strengths as measured on various hydrometer scales at 60°F (16°C)

Salinometer degrees	Specific gravity	Baumé degrees	Twaddell degrees	Per cent salt by weight	Salt (g) per litre of water
0	1.000	0.0	0.0	0.000	0.0
10	1.019	2.7	3.8	2.640	27.0
20	1.038	5.3	7.6	5.279	55.6
30	1.058	7.9	11.6	7.919	85.8
40	1.078	10.5	15.6	10.558	117.7
50	1.098	12.9	19.6	13.198	151.7
55	1.108	14.1	21.6	14.517	169.5
60	1.118	15.3	23.6	15.837	187.9
65	1.128	16.5	25.6	17.157	208.6
70	1.139	17.7	27.8	18.477	226.2
75	1.149	18.8	29.8	19.796	246.3
80	1.160	20.0	32.0	21.116	267.1
85	1.171	21.2	34.2	22.436	288.7
90	1.182	22.3	36.4	23.755	310.8
95	1.193	23.5	38.6	25.075	333.9
100	1.204	24.6	40.8	26.395	357.9

HYGROMETERS AND MOISTURE METERS

The measurement of moisture content or humidity of the air is important for many drying and smoking operations; an instrument called a hygrometer is used for this purpose. The moisture of the final product can be determined by weighing (as mentioned earlier) or by using a moisture meter.

Hygrometers

Horsehair: The simplest and crudest type of hygrometer is the so-called horsehair hygrometer. Certain substances such as horsehair, catgut and paper absorb water

depending on the relative humidity. As they take up water, they expand and can be made to operate a pointer on a scale. These devices are, however, almost impossible to calibrate and are very unreliable.

Wet and dry: Wet and dry hygrometers consist of two thermometers; the bulb of one is kept moist and is usually in a muslin bag, the other is kept dry. As air blows over both thermometers, water evaporates from the wet bulb and cools it. The difference in temperature between the two, known as the wet bulb depression, depends on the relative humidity. After reading the dry bulb temperature and the wet bulb depression, the relative humidity is obtained from a table which gives humidities for a range of dry bulb temperatures and wet bulb depressions.

The wet and dry bulb hygrometer is the most reliable method of measuring relative humidity. However, the following rules should be followed:

- keep the wet bulb moist with clean water
- if there is no reservoir, after moistening, leave for half a minute before reading
- read both bulbs within a few seconds
- the wet bulb must be downwind
- air speed must be more than 1 metre per second

Other types of hygrometers, based on different principles, are available but none of them are very robust and will not be considered here.

Moisture meters

The standard method of determining moisture content has been mentioned earlier. A known weight of sample is dried overnight in an oven at about 105°C and re-weighed; the percentage moisture is then calculated. This method is very accurate and reliable but is slow. There is a commercial instrument, which uses an infra-red lamp, for detecting moisture. This is suitable for dry materials such as fish meal and the moisture content can be found in about 20 minutes. For wetter fish flesh, there is a method whereby a known weight is heated in a liquid which does not mix with water (e.g., toluene) and the water is collected and measured. This method takes about an hour and, since toluene is highly inflammable, it should be used only by trained technicians.

Various types of meters have been developed for rapid estimation of water content. One of these depends on electrical conductivity changing with moisture content. Although it is suitable for seeds and grains, it has not proved to be very successful with other products because salt affects the instrument. In another method, a known weight of the sample is mixed with calcium carbide; acetylene gas and heat are produced and, if this reaction is carried out in a sealed container, the pressure generated can be measured on a Bourdon gauge which is graduated for moisture content.

FLOW METERS

Measurement of the flow of gases is carried out in the fishing industry, mainly in relation to air circulation in blast freezers (and blast thawers) and smoking kilns. Various instruments are available which give a direct or indirect reading. Direction of air flow can be found simply by holding a 'streamer' at arm's length in the air current.

Anemometers

Anemometers are delicate instruments which measure air flow by the speed of rotation of a small fan. They are placed in the desired position, the counting mechanism is switched on and then turned off after an accurately timed period, say, one minute. This operation is then repeated several times. One of the problems with

this sort of meter is that, however carefully they are made, some energy is lost in driving the fan. They cannot be used for slow air speeds of less than 17 metres a minute. Also, the mechanism is extremely delicate and is damaged by high temperatures and smoke. Direct reading anemometers tend to be rather expensive.

Velometers

Another means of measuring air flow is to measure the force exerted on a pivoted vane, placed in the air stream. A velometer is an instrument in which the vane moves in a specially shaped channel and the force is opposed by a small spiral spring; a pointer attached to the vane moves across the scale. Velometers can be placed directly in the air stream or can be connected by specially-designed inlet and outlet tubes to the air or smoke.

Pitot tubes

The pitot tube measures gas flow by the determination of pressure difference. The air speed affects the height of the liquid in the tube according to a known mathematical relationship. One type of pitot tube has a detecting head, which must face into the air stream, and at the other end there is a two-way junction which is connected via tubes to an inclined manometer. The manometer measures the pressure difference between what is called the impact pressure and the static pressure; it is very useful as it can detect small pressures.

Anemometers, velometers and pitot tubes are used for 'spot' tests and, generally for any measurements at any time, a number of readings are made and an average is obtained. In some instances, constant monitoring is required. A number of devices are available, most of which depend on measuring the difference in pressure in front of, and behind, an obstruction in a flow of gas or liquid. The orifice meter is the most common of these.

Orifice meter

After the gas or liquid is forced through the orifice, it does not immediately spread out but forms a 'neck'. The pressure here is lower than in the main stream and the difference in pressure is measured with any suitable pressure-measuring instrument and the velocity is calculated. Orifice meters are simple, cheap and robust but, as they do obstruct flow, the pump or fan which is producing the air flow has to generate additional pressure to operate the meter.

SMOKE METERS

The optical density (OD) of smoke is measured by determining how much light, from a lamp of known brightness, will penetrate a given, fixed distance. Although this system can detect only droplets in the smoke and not the vapours, it gives a useful measure of the smoke thickness. Light is focussed through a lens system on to a photo-electric cell and the current produced is measured on a suitable meter which gives OD per unit distance. Both the lens and the photo-electric cell must be protected against the tar deposits from the smoke; electrically-heated glass windows are placed in front of each. The cell and the light source must be in the kiln but the meter can be some distance away.

Other types of smoke meter can 'meter' the smoke in much the same way as an electricity meter shows how much electricity has been used. In another type, the smoke density is recorded on a graph; it is much more expensive and, although it has a number of advantages, has the disadvantage that the detecting and measuring devices are fixed together.

Wet fish handling and preparation

There are many different types of fish products available to the consumer but most of them will have undergone some sort of initial preparation before processing. This preparation can be in the form of cutting the fish in a particular way to produce the raw material necessary for future processing. Due to the delicate nature of the fish and the rapid rates of deterioration that can occur if the fish is treated badly, it is extremely important to handle it hygienically and carefully during all stages of preparation. This session is designed, firstly, to clarify some of the ways in which the initial preparation can be done and, secondly, to give guidelines to the hygienic preparation of fish before onward processing.

DEFINITIONS OF SOME TERMS USED IN FISH PREPARATION

1. *Fillet* – a strip of flesh cut from the fish parallel to the line of the backbone.

Block fillet – flesh from both sides of a single fish joined together usually along the backbone.

Single fillet – flesh from one side of the fish.

Fish can be filleted either by hand, using knives or, in the case of many of the more common European and American species, using filleting machines. Fish are often filleted prior to sale fresh as well as prior to freezing, smoking, canning and production of mince products.

2. *Gutted fish* – fish from which the guts have been removed.

Gutting is often done at sea prior to storage on ice or before freezing in vertical plate freezers on 'freezer trawlers'. Gutting is usually achieved by cutting the fish along the ventral surface from the vent to the gill opening and removing the intestines. In many cases, the head is removed at the same time as the fish are gutted.

3. *Split fish* – fish are often split during preparation for smoking or drying. The purpose of this is usually to increase the surface area of the fish so that it can dry more quickly or take up flavours of salt, smoke or other condiments used during processing, more uniformly. Most of the methods used for splitting fish remove the guts but do not remove bones except perhaps for the head.

4. *Boned fish* – the flesh of the fish from which most of the bones have been removed. For instance, a fillet may contain some small pin bones or ribs but it is often described as boned.

5. *Boneless fish* – flesh of the fish from which *all* the bones have been removed.

6. *Dressed fish* – fish which have been prepared for cooking or prepared in a particular way for presentation purposes.

GUTTING FISH

It is normal practice in many temperate water fisheries for fish to be gutted as a matter of course as soon as they are landed on the deck of the catching vessel. Gutting of cod, for instance, is so routine that a whole cod is almost impossible to buy in the UK and the trade talks of gutted cod as whole fish. The purpose of gutting is to remove one of the major bacterial concentrations from the fish and so minimise the risk of contamination of the fish flesh by gut bacteria. It is generally accepted that coldwater white fish keep better in ice when gutted. The little work that has been done on tropical species suggests that there are advantages in gutting tropical fish but these are often marginal and, in many communities, there is a resistance from the consumer in accepting fish that is not whole. For this reason, it is often not practical or advantageous to gut fish in tropical developing countries. When gutting, it is extremely important that all the guts are removed, the belly wall of the fish is not broken and the belly cavity is thoroughly washed after gutting. If this is not done, the bacteria which are released from the guts during removal will contaminate the flesh and the whole operation will have been in vain.

FILLETING

A high demand for convenience foods in the developed world constitutes a large market for boned fish. The majority of fish eaten by people in the UK and Western Europe is prepared into fillets or other convenience products in processing factories before it is distributed to wholesalers and retailers, often as a frozen product.

Fillets must be prepared with great care and under strict conditions of hygiene because the flesh, once cut from the body of the fish, is very susceptible to the action of bacteria on its large exposed surface area.

The phenomenon of *rigor mortis* is important as far as the fish filleter is concerned only when he is handling very fresh fish which have not yet entered *rigor* or are actually in *rigor*. If a fish is filleted pre-rigor the fillet will enter *rigor* off the bone and, since there is no skeleton to support the flesh, the fillet will shrink as the muscles contract. If the fish is in *rigor* during filleting, the physical difficulties of cutting the rigid fish will probably produce a bad fillet which will shrink once removed from the bone. These problems usually only occur when filleting on board fishing vessels at sea.

HYGIENE

Bacterial contamination of fish flesh is a major cause of spoilage and, if the flesh is contaminated by pathogenic bacteria, it can cause serious illness or even death amongst consumers. If fish are kept clean and at chilled temperatures contamination can be kept to a minimum and the growth of any bacteria that are present is reduced.

One of the most important requirements when we handle fresh fish is that of adequate supplies of clean water. More than 90 per cent of the bacteria present on the surface of fish can be removed by thorough washing with clean water. The water should be filtered and chlorinated, otherwise it may introduce bacteria to the flesh of the fish which may be pathogenic and in the long run do more harm than good. Water which is going to come into direct contact with fish should be of similar quality and intensity of chlorination as drinking water, i.e. about 0.1 to 0.3 ppm residual chlorine. Water used for washing down premises etc. can, and should, be of higher residual chlorine which could be up to 20 or 30 ppm.

Cleanliness is required at every stage of fish handling and preparation. All working surfaces must be made from materials which do not soak up water and they should be cleaned daily. Similarly, all equipment and tools must be kept clean. Personal hygiene of staff is essential and adequate washing facilities, including the provision

of soap, brushes and clean towels, should be available and should be used before commencing work, after handling any contaminated materials and after going to the lavatory.

Metal working surfaces, sinks etc. are preferable, as are composition cutting boards. Wooden cutting boards of a suitable non-resinous hardwood are permissible but additional care should be taken to ensure their cleanliness. Floors should be waterproof and well drained. At the end of each working day all surfaces should be thoroughly washed down with a suitable detergent.

The handling fish receives before and during preparation will affect the quality of the final product. Fish should be kept in boxes or similar containers and should not be piled on the floor, nor should they be thrown around or walked over. Fish should at all times be handled with care to prevent physical damage (fish flesh is easily bruised); they should be clean and kept clean. Wet fish should be at chill temperature and should be shielded from direct sunlight, particularly in the tropics where ambient temperatures are high. Fish deteriorate very rapidly at high temperatures. Cut fish are more liable to bacterial contamination than whole fish and tools and equipment which come into contact with cut fish must be clean. Fillets should be processed or packed and chilled immediately after preparation.

REQUIREMENTS FOR FISH HANDLING PREMISES

Detailed below are outlined specifications for buildings in which fish are handled and suggestions for a code of practice that should be followed when handling fish.

1. Where possible, all preparation, processing and packaging should be carried out in one building.
2. Buildings should be single-storeyed; drainage and handling fish is easier on a single level.
3. Floors should be smooth surfaced, but non-slip, well drained and waterproof. As far as is possible they should be resistant to attack by fish oils, offal and brine. High density concrete containing granite chips can be used, although clay tiles are better.
4. The floor surface should be carried up the walls or any permanent fixtures for a height of at least 15 cm (6 inches).
5. Floors should slope into the drainage system to facilitate washing down.
6. Drainage channels should be accessible and traps should be installed before discharge into any sewer or soakway. Traps should be easily and frequently cleaned. Drainage channels should be arranged away from through areas; if not, they should be covered with flush fitting removable gratings.
7. Walls should be waterproof and have a smooth surface. Tiles can be used on walls where the working tables are against the wall. All other wall surfaces should be painted, preferably with a hard gloss paint.
8. Doors should be flush fitting and well painted to give a waterproof and washable surface.
9. Windows should be of simple construction with a few large sheets of glass, not numerous small sheets.
10. All metalwork should be painted thoroughly to prevent rusting.
11. In tropical countries, efficient fly screening is essential. All doors and openable windows should be screened. Self-closing screen doors should be fitted at all normal points of entry and exit to and from the working areas.
12. Ceilings should have, as far as is possible, a continuous unbroken surface, be painted in a light colour and be easily washed. In tropical climates, insulation above the ceiling may be required to reduce over-heating.

13. Good ventilation is essential and, in the tropics, all ventilation openings must be screened. In very hot and humid climates, an air-conditioning system may be justified. In this case, a qualified engineer should be consulted.

14. All equipment must be easy to clean. All work surfaces should be of stainless steel or aluminium alloy. Cutting boards of composition material are preferable but if not available cutting boards of hard non-resinous wood should be used.

15. Containers for fish and brine should be made from stainless steel, aluminium alloy or a suitable plastic. Wooden fish boxes can be used but they are more difficult to keep clean.

16. All electrical installations should be properly earthed with waterproof power points. They should be sited well above floor level.

17. A piped supply of clean, drinking quality water should be available. If suitable piped water is not available a filtration and chlorination plant should be installed to treat the raw water supply.

18. A regular cleaning routine must be established for the whole premises to ensure that standards of hygiene are maintained. It is important that adequate supervision is given during cleaning.

19. Detergents and sterilants should be used for cleaning. Detergents help to remove dirt, sterilants kill bacteria. Many detergents also have sterilising properties. A detergent must be used to remove dirt, followed by a sterilant to kill any remaining bacteria. If water chlorination equipment is on site, high levels of chlorine in the water can be used to sterilise.

20. A piped hot water supply should also be available. Detergents are far more effective when used in hot water.

21. High pressure hoses should be used for washing down if at all possible.

22. Adequate washing, changing and lavatory facilities should be installed but not in the fish working area. Washing facilities should also be installed in the fish working area.

KNIVES

Knives form an important part of a fish processor's equipment. There are various types of knife used in fish preparation which have specific uses. However, there are many makes and designs of knife all with the same function. It is often a matter of personal preference as to which knife a particular fish processor uses.

The filleting knife is usually a long, thin-bladed instrument. The blade can be anything from 15 to 20 cm long and it is often only 1 cm or so wide. The blade needs to be slightly flexible so that it can bend when put under pressure during the filleting operation. The knife used for block filleting is a short-bladed knife about 7 to 10 cm long by about 1 cm wide with some flexibility to accommodate pressure during use. The gutting knife has a short blade, often only 5 to 7 cm long, which does not need to be very flexible.

Traditionally, fish knives have been made of tempered carbon steel with wooden (usually rosewood) handles. These knives have the great advantage of being easy to sharpen and they remain sharp once sharpened. However, without regular cleaning, the blades can rust and the handles become waterlogged and, therefore, difficult to clean. Recently, there has been a change to stainless steel bladed knives which have the great advantage that they do not rust. However, a stainless steel knife will not sharpen as well as a normal steel knife nor keep its edge for so long. With the introduction of stainless blades has come the use of moulded plastic handles for fish preparation knives. These are easily cleaned and very hard wearing compared with wooden handled knives.

(2) Those concerned with handling fish must be constantly reminded that they are food and must be treated in the same way as their own food, both in avoiding damage and in keeping to high standards of hygiene.

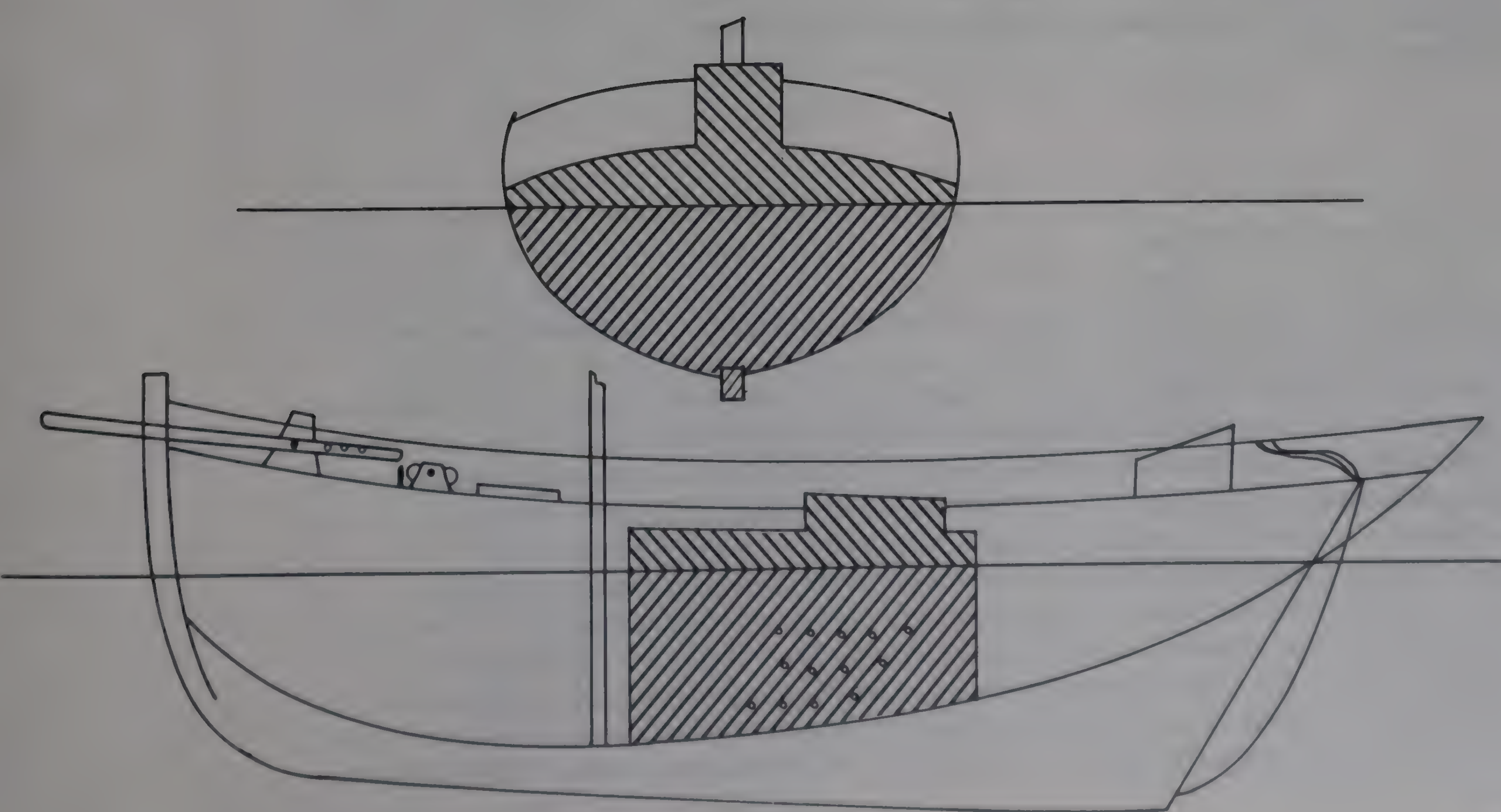
One cannot expect any better standards of hygiene than those adopted by the individual when handling fish for his/her own consumption. If these standards are not satisfactory, a more general approach is needed in association with other public bodies concerned with education and health.

Live carriage of fish

Carrying fish alive to a market where the consumer can buy them must be one of the oldest methods of ensuring that consumers can get fresh fish. This method was used extensively until ice became freely available in Europe and it is still widely used, more particularly for handling freshwater fish, especially those cultivated in ponds. The fish farmer has the same advantage over the fishermen which the live-stock farmer has over the hunter; in the short term, it is possible to choose when to put the crop on the market. Since cropping can be controlled, it is possible to sell the catch alive and this is the freshwater fish farmer's normal practice. The fish can be sold with a minimal weight loss, no expensive equipment is needed and no preparation of the fish is required. Some people buy live fish in preference to dead ones, particularly at festival times, and this can be an important selling point. Some cultured marine fish are also sold alive; where this is done, it is invariably to meet a market demand in places where people will pay extremely high prices for the privilege of eating fresh marine fish.

It used to be common practice in Europe to sell fish such as cod, which had been caught by hand lining, alive; even fish caught in short hauls of the beam trawl were sometimes kept alive. The vessels in which the fish were carried were specially designed and had live wells built into them (see Figure 5). These are simply

Figure 5
Well vessel.



constructed by building bulkheads athwartships, which can be kept watertight, and boring holes at intervals in the bottom of the vessel. This ensures an exchange of water between the live well and the sea outside. The exchange, however, is not very efficient and only limited numbers of fish can be carried in this way. This method is still practised in the Bahamas where fish are caught by handline in the coral reefs and live for a period of days in live wells because the water is silt-free and unpolluted.

PHYSICAL NEEDS OF FISH

Most of the remarks made in this section apply to molluscs, crustaceans and other aquatic animals as well as fin fish. The section is, however, based primarily on the needs of the true fish. Fish have really only two basic needs; they must feed in order to provide material for energy and for growth and they must carry out the processes of respiration which provide them with energy.

Since we normally wish to keep fish alive for relatively short periods there is no need to consider feeding them during the time that they are being carried. It is, of course, perfectly possible to hold fish in tanks or ponds and to feed them there but when carrying fish one wishes to limit the quantity of water and thus the fish are always very crowded. If you attempt to feed fish under such crowded conditions, it is very likely that the water would rapidly become polluted from waste food and faeces both of which have high oxygen demands. It is, in fact, usual to starve fish during transit.

Respiration is an entirely different matter. If fish are unable to respire they soon die. The main need here is to ensure that an adequate supply of oxygen is provided and since most fish can obtain oxygen only by passing water over the gills, the oxygen must be in solution. There are of course some exceptions to this rule; many of the catfish can travel in very little water and obtain the required oxygen through the damp surface of their gills or, in some cases, through the body skin. This applies equally to other fish which have accessory air breathing organs, such as the climbing perch. But for most fin fish the limiting factor on the number of fish which can be carried in a given container for a given time is the *oxygen content of the water.* The oxygen content can of course be replenished by one of several methods which will be discussed later but, nonetheless, there are physical limits to the rate at which the oxygen can be replaced in the water. At the same time it is necessary to remove the carbon dioxide produced in respiration, as well as other waste products such as ammonia.

CARRIAGE OF SEA FISH

When carrying fish in a live well vessel it is usual to replace oxygen-depleted water by a simple exchange of water with that outside the live well. Most of the vessels which carry live wells for fin fish are of very simple construction. None of them seem to employ a pump for exchange of water. A pump could very easily be rigged to drive from the main engine by means of a belt and this would provide more rapid exchange than is obtained by the holes drilled in the bottom of the vessel. Exchange of water is more effective when the boat is moving forward. The fish often look quite healthy while the vessel is at sea but rapidly become moribund when it enters harbour, even in places where there is a good exchange of clean, well oxygenated water. When the vessel must enter an area of unsafe water, before the fish can be sold the holes are usually stopped with wooden plugs. As mentioned previously, exchange is much better while the vessel is moving forward and could no doubt be improved by using a venturi bailer of the type often used in racing sailing boats.

CARRIAGE OF FRESHWATER FISH

Farmed freshwater fish are usually taken to market either in tubs, or similar containers, or in tankers. Whatever type of container is used, it is necessary to take a quantity of water to market as well as the fish and it is thus important to carry as many fish as the container will allow.

The weight of fish which will be carried depends on a number of interrelated factors which affect water quality. The oxygen dissolved in the water is used by the fish in respiration and there are oxygen demands from excretory products and other biological waste. The oxygen must be replaced as it is used and this may be achieved by: aeration using mechanical or electrical pumps; the venturi effect in a moving vehicle; or by using compressed gas liberators. In the simplest system of all, where for instance a small tank is carried on a bicycle, the carrier may be able to move only a few fish at a time; the only way in which he can keep fish alive for any length of time is to arrange to exchange small quantities of water at intervals along his journey.

The venturi effect is difficult to apply and is seldom used. Electrical pumps are somewhat easier to manage than mechanical pumps in small systems, but for a large system a diesel or petrol engine driven pump is perfectly satisfactory. Care must be exercised in the siting of the intake to ensure that clean air, unpolluted by exhaust fumes, is drawn in. Where bottled air or oxygen is easily obtained, this provides the simplest means of oxygen replacement. The valve must be carefully regulated to ensure that gas is supplied at an appropriate rate; oxygen is expensive and should be supplied only at a rate at which it can be absorbed. For practical purposes, compressed air is used more frequently than oxygen since the action of the bubbles in circulating the water mass exposed to an air surface is at least as important in providing for gaseous exchange as is the supply of bubbles.

THE PRACTICALITIES OF CARRIAGE

As noted earlier, it is not usual to feed fish during carriage; it is, in fact, commonplace to ensure, if possible, that the gut is empty before sending fish to market. There are two reasons for this: firstly unfed fish are livelier than fish which have just been fed because they are not using energy in digestion and assimilation; secondly, and more important, is the fact that, if the fish defaecate in the water, the faeces have a high oxygen demand and this reduces the quantity of fish which could be carried. It is, therefore, usual to catch fish which are to be marketed live the day before they are to be sent to market and to see that no food is given.

The tank or tanker should be filled with pondwater and well aerated before the fish are transferred to it. This will ensure that there is no sudden change of pH and no sudden temperature shock. Some fish are more sensitive than others to changes of pH and temperature but it is common sense to see that conditions are maintained close to the optimum for any particular species during carriage.

Water can hold more oxygen in solution at low temperatures than higher ones, while fish require more oxygen for respiration at higher temperatures. Thus a tank of given volume can safely hold fewer fish at high temperatures than low ones. In Europe, it is thus a common practice to add some ice to the water in which fish will be carried. This works satisfactorily with common carp raised in Europe, which can be kept alive at temperatures near freezing and come to no harm. Whether carp accustomed to living in the tropics would tolerate such extreme conditions is not known. Tropical fish, such as *Tilapia* sp., are likely to die if the water temperature falls below 15°C, the exact temperature being dependent upon the species, but it is good practice to operate at the cooler end of the temperature range. It is also good practice to arrange that the tank or tanker is insulated so that temperatures do not fluctuate too widely during transit.

The important question is what weight of fish can be carried in a given volume of water. This depends on the species, since different species have different levels of oxygen demand; rainbow trout, for instance, need more dissolved oxygen in the carriage water than do common carp. It is possible to carry common carp at a ratio of 3 parts of water to 1 part of fish. For example, a 5 000 litre tanker could carry 1 tonne (1 000 kg) of carp in 3 000 litres of water. For very short journeys, it is possible to carry carp at a ratio of 2 parts water to 1 part fish. As mentioned earlier, the temperature should be kept as low as possible and this means that there are advantages in travelling at night rather than during the day whenever this is practicable. Carriage at such levels is possible only with good aeration; this is best arranged through air stones of the same type as those used in aquaria or, better, the larger ones now manufactured for use in ponds. Where no aeration can be practised, much smaller quantities of fish should be carried; the exact quantity could be determined only by experiments. The other points made all apply: i.e. fish should be starved before travelling; the temperature should be kept as low as is practicable; if water exchange is carried out the water should be of similar pH and temperature to that which it replaces.

EATING QUALITY OF FISH SOLD LIVE

It is sometimes suggested that fish sold alive should be of better eating quality than those which have been killed some time before sale. This depends on what is meant by quality, of course, but it is a fact of elementary biochemistry that a well-fed and rested animal, with high glycogen content in the liver, killed without struggling, provides the best eating quality. This is because the glycogen is broken down to sugar during the period following death. Little, if any, work seems to have been carried out to investigate the biochemical changes which take place during live carriage; however, it would be expected that fish which have starved, struggled and lived in poorly oxygenated water would be of poorer eating quality than those which have been killed and promptly iced.

MOLLUSCS

The commoner molluscs — cockles, clams, oysters and mussels — almost all grow in the littoral or inter-tidal zone. Thus, all of these animals can be carried dry. It is common practice in Europe to carry such animals in sacks or barrels. Any similar container is suitable. It is preferable to wash off any mud before carrying the animals very far and it is usual to spray them occasionally with seawater, mainly in order to keep them cool. The animals will normally keep their shells closed while travelling and, even at tropical temperatures, can be kept alive for one or two days.

Many of these animals feed by filtering the water to catch plankton which forms their principal food. In filtering the water, the animals also ingest any bacteria which happen to be available in the water. Since many of them grow in areas where sewage enters the water, it is perfectly possible for them to contain large numbers of the bacteria responsible for diseases such as *typhoid, paratyphoid* and *cholera.* When the animals grow in clean water away from sewage, they are of course perfectly harmless. Where there is any doubt at all about their purity the health laws in European countries require that the animals should be cleansed by holding them in clean water for a period before sale. They are held in pits of clean water and, during holding, they open and attempt to feed and of course respire. There is no, or very little, food present in the water; thus the animal empties its gut not only of the faeces but also of any bacteria which may have been present on the feeding grounds.

It is important particularly that oysters, which are commonly eaten alive, should be cleansed of any possible contamination before sale but mussels are also treated because they are often only very lightly cooked. Cleansing of cockles and clams is also desirable because these animals otherwise tend to contain rather large quantities of mud or sand which are unpleasantly gritty in the mouth.

CRUSTACEANS

Most crustaceans are rather delicate and it is difficult to keep them alive even in aquaria. It would thus be almost impossible to market large quantities, even in well oxygenated water. Some species, for instance, the lobsters and rock lobsters, can be carried alive and dry. Some of the larger prawns can be similarly treated. The precautions which need to be taken are obvious: the animals should be exposed to stress as little as possible; they must be handled with great care so that they are not crushed; and they must be packed so that they cannot move. It is also essential that they should be protected from rapid changes of temperature. The exact method of packing varies with the species; the rock lobsters, for instance, must be kept separate from one another or the spines of one animal will penetrate and kill another. Such animals are at present so valuable that it is possible to carry them over distances of thousands of miles by air and still show a profit.

CARRIAGE OF EXOTIC AQUARIUM FISH BY AIR

This is rather a special case of live carriage. Since air freight is so expensive it is particularly desirable to keep the weight as low as possible. The fish are themselves usually quite small and so they can be carried over long distances in crowded conditions.

The usual method of carriage nowadays is to put the fish into a plastic bag partially filled with water, which is itself carried in an insulated cardboard box. The usual insulation is one to two inches of polystyrene foam. The fish are starved for 12 to 24 hours before being freighted; they are transferred into a bag which is almost full of water from the container in which they have been living; most of the water is then displaced by blowing oxygen into the bag so that the fish travel in water under a layer of pure oxygen. This keeps the level of dissolved oxygen in the water high during the time the fish are travelling — never more than 24 hours. At most modern airports, it is possible for the bags to be re-oxygenated should the aeroplane be delayed.

It is important that the fish should be held in quarantine for a week or two before they are shipped so as to ensure that they are disease-free. It is now possible to carry marine fish as well as freshwater fish to those countries where fish fanciers will pay high prices for colourful exotic fishes.

CARRIAGE OF LIVE BAIT

Tuna pole fishing vessels require large quantities of live small fish such as chum. When a school of fish is sighted they are brought alongside the fishing vessel by throwing live bait to them. Anchovies are a very popular bait and these fish, while hardier than most of the other clupeoids, are nonetheless somewhat difficult to carry. They have a schooling habit and the tank must be large enough for them to form a school and to swim around the tank in a circle.

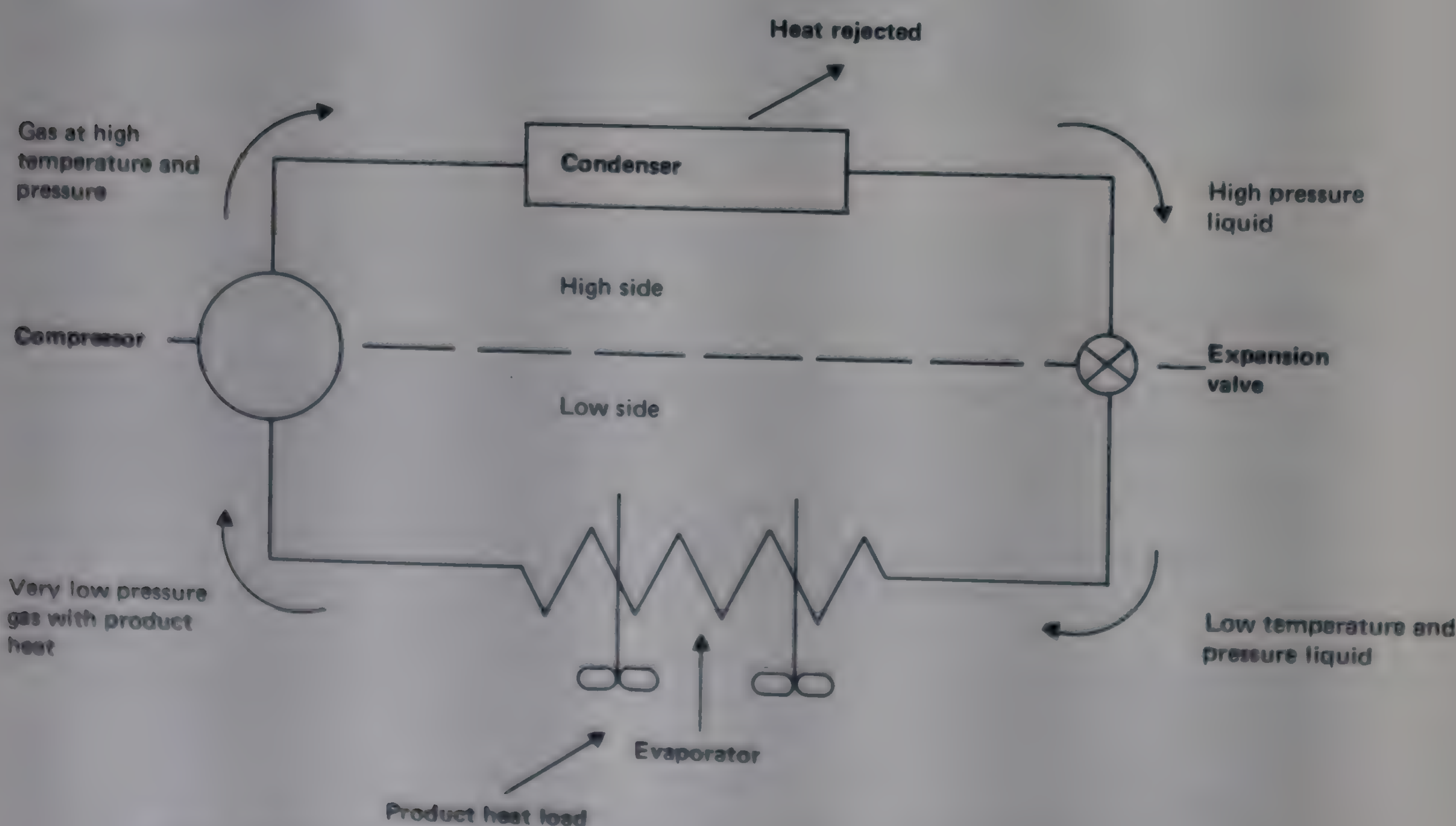
The tanks themselves should be constructed of material which cannot poison the fish by solution of poisonous substances; the interior surface should preferably be painted white or finished in a light coloured material. Aeration is usually by mechanical pump and can be quite vigorous. In the simplest possible system, the water can be allowed to enter a live well through holes in the bottom of the boat and to pass through a grating or fine meshed net which forms the after bulkhead of the live well, the water being pumped or baled over the side aft of the grating.

Chilling: the manufacture of ice

The use of ice or snow to cool drinks or preserve food was discovered in Europe many centuries ago. The Romans sent runners into the hills to bring down snow; naturally occurring ice was sawn from frozen lakes and ponds during the winter and stored in specially constructed insulated ice houses, usually below ground. Such ice was expensive and only the rich could afford to use it; at that time, marine fish were commonly brought to market alive in well boats. As industrialisation increased, so did the need to preserve foodstuffs, in particular fish; some highly desired European fish species earned their popularity because they deteriorated less rapidly at ambient temperatures than some other species. In England, during the 18th and 19th centuries the use of ice to preserve fish became commonplace. Farmers used to flood their fields in winter so that ice was collected as a regular crop. It was cut and carted to a warehouse, some 2 000 to 3 000 people being engaged in the collection. One ice house in London was 18 feet underground and had walls 8 feet thick; the storage capacity was about 10 000 tonnes, so that probably about twice this amount was used each year. Ice was also brought to Britain from Norway and even from America.

Late in the 19th century the first artificial ice plants were installed. The principles of ice manufacture developed then continued to be used for very many years. Ice is

Figure 6
Refrigeration cycle



Source: Adapted from Fig. 2–6, p. 23, *in* Marine Refrigeration and Fish Preservation, by John T. Mead. Business News Publishing Company, Birmingham, Michigan, U.S.A. (1973).

made by allowing water to come into contact with a cooled surface which takes heat from the water. In order to cool the ice-making surface, a refrigerant is used; refrigerants are gases at atmospheric temperatures and pressures but can be liquified by moderate pressure. When the pressure is released, the refrigerant evaporates rapidly and, in doing so, it absorbs heat from the surrounding surfaces. Ammonia, which has a high latent heat of evaporation, is widely used as a refrigerant; it is toxic and, in certain conditions, combustible and explosive; being highly soluble in water, it may contaminate wet fish. Carbon dioxide is much less commonly used, although it is odourless and there is no fire risk, because higher working pressures are needed. The halogenated hydrocarbons known by trade names such as Arcton and Freon are commonly used. Although refrigerant trade names are still widely used, they should be now named according to an internationally agreed numbering system. Block ice plants commonly use ammonia; this has the advantage that ammonia is widely available, whereas some of the other refrigerants may be difficult to obtain in isolated places in the tropics.

In the refrigerating machinery used in refrigerators, freezers and cold stores, and in ice-making machines and plants, a liquid refrigerant is passed to an evaporator which consists of a series of coils; in these, the liquid becomes a gas drawing the necessary heat from the coils which are, therefore, cooled. If the coils are placed into fluid, the fluid is also cooled. The refrigerant gas is passed through a compressor, which raises the temperature and pressure of the gas, and hence to a condenser, which is cooled by air (or more usually by moving water), and in which the refrigerant returns to the liquid state. From the condenser, the liquid passes through an expansion valve to the evaporator. The refrigeration cycle is illustrated in Figure 6.

TYPES OF ICE AND ICEMAKERS

Ice may be made in block form, the blocks being of various sizes, shapes and weights of from 12 to 150 kg, or as 'small ice', a term used to describe many kinds of ice made in small pieces. The various types of ice-making plants are named after the type of ice which they produce, so that there are block ice plants, flake ice plants, plate ice plants and so on.

Block ice plants

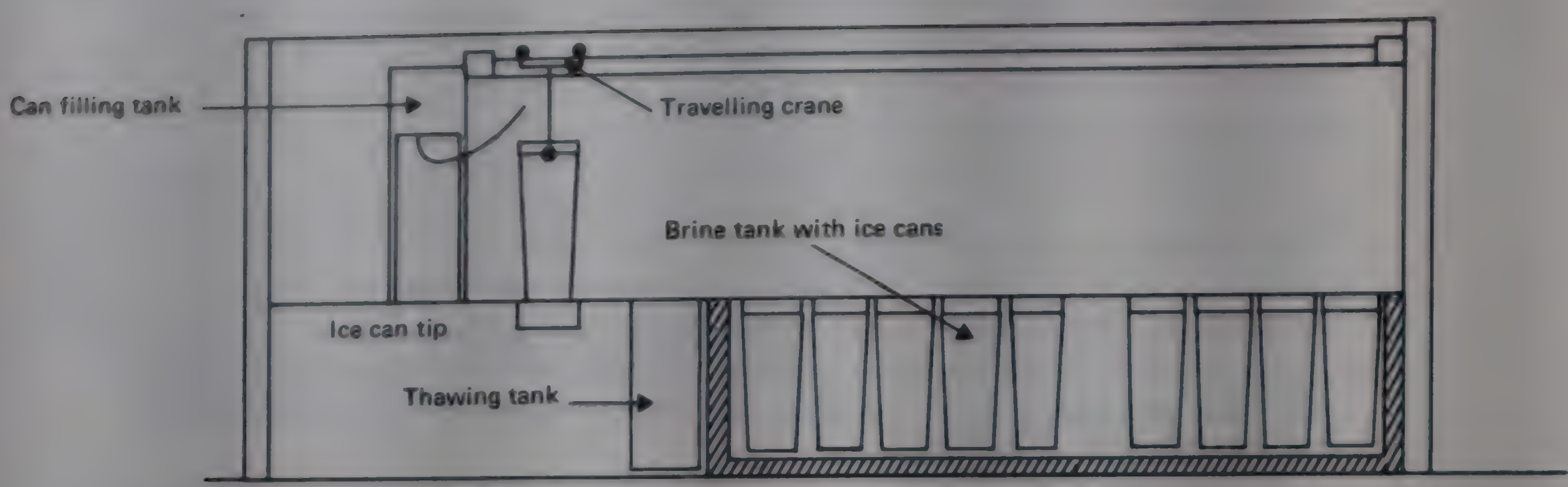
Until recently most ice was made by putting rectangular moulds or ice cans in a tank of brine fitted with evaporator coils. Sodium chloride or calcium chloride brines may be used, the latter being more common; both are likely to corrode the cans unless very pure. Typically, block ice plants produce ice in 12 to 24 hours. The blocks are usually stored in refrigerated, insulated stores but small plants which have a rapid turnover may use insulated unrefrigerated stores.

Before block ice can be used to chill fish, it must be broken or crushed into small lumps. Mechanical crushers are used in the larger ports and hand crushers are available. Since crushed ice, having a larger surface area than block ice, melts more rapidly, small boats often find it more convenient to take the blocks to sea and crush by hand as the ice is needed.

Block ice plants occupy a relatively large amount of space and produce ice rather slowly; the large blocks, which may weigh up to 150 kg, are inconvenient to handle and the irregular shaped lumps of ice produced by crushing can cause physical damage to delicate fish. Block ice has an advantage over other forms of ice in that it melts relatively slowly while still in block form. Where ice is required in large amounts or where it must be transported for long distances, block ice is unlikely to be replaced by other forms.

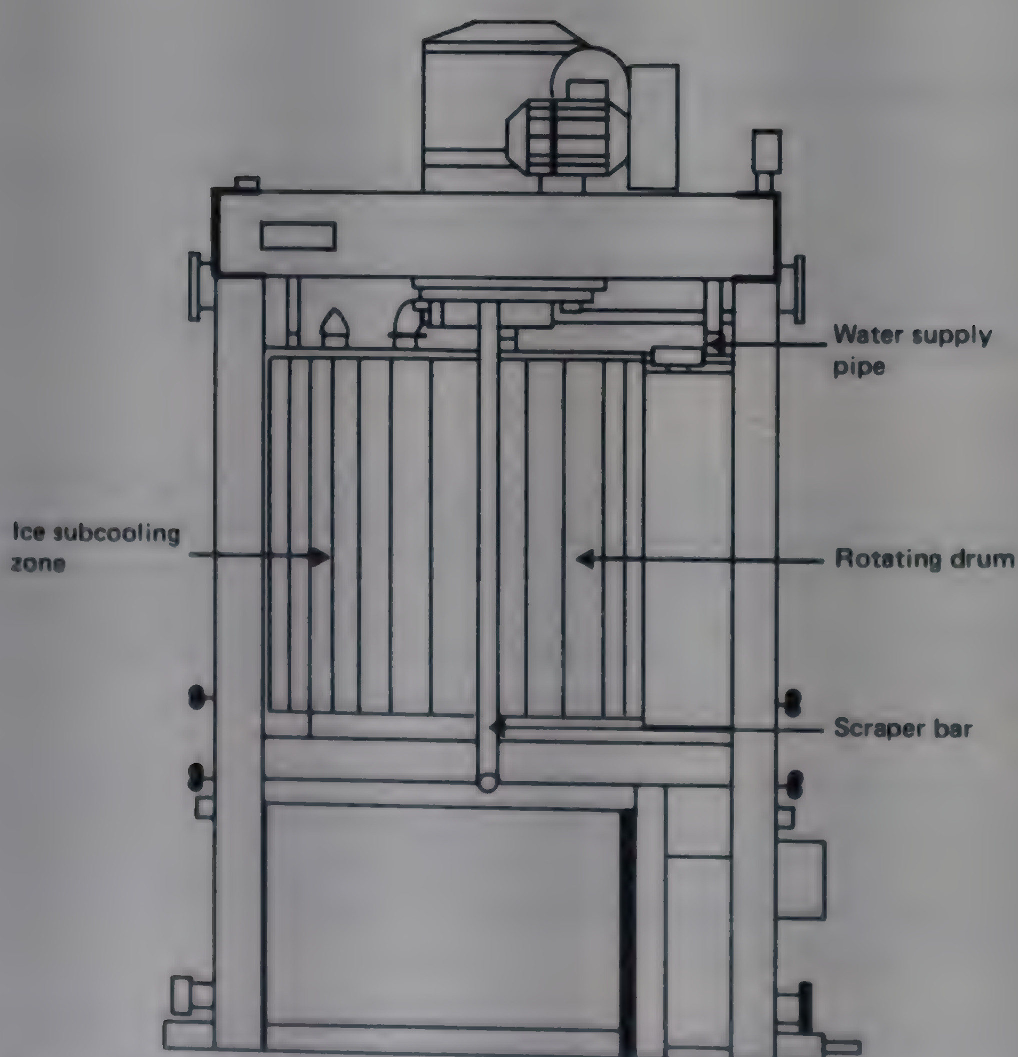
In a modern plant, the cans are handled by means of an electrical travelling crane. The cans are filled automatically (see Figure 7) and then lowered into the refrigerated brine. When the water has frozen, the cans are lifted out, lowered into a warm thawing tank so that the ice is released, and then lowered on to a tip which

Figure 7
Block ice maker



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1974) FAO Fisheries Report (59 revision 1).

Figure 8
Flake ice machine



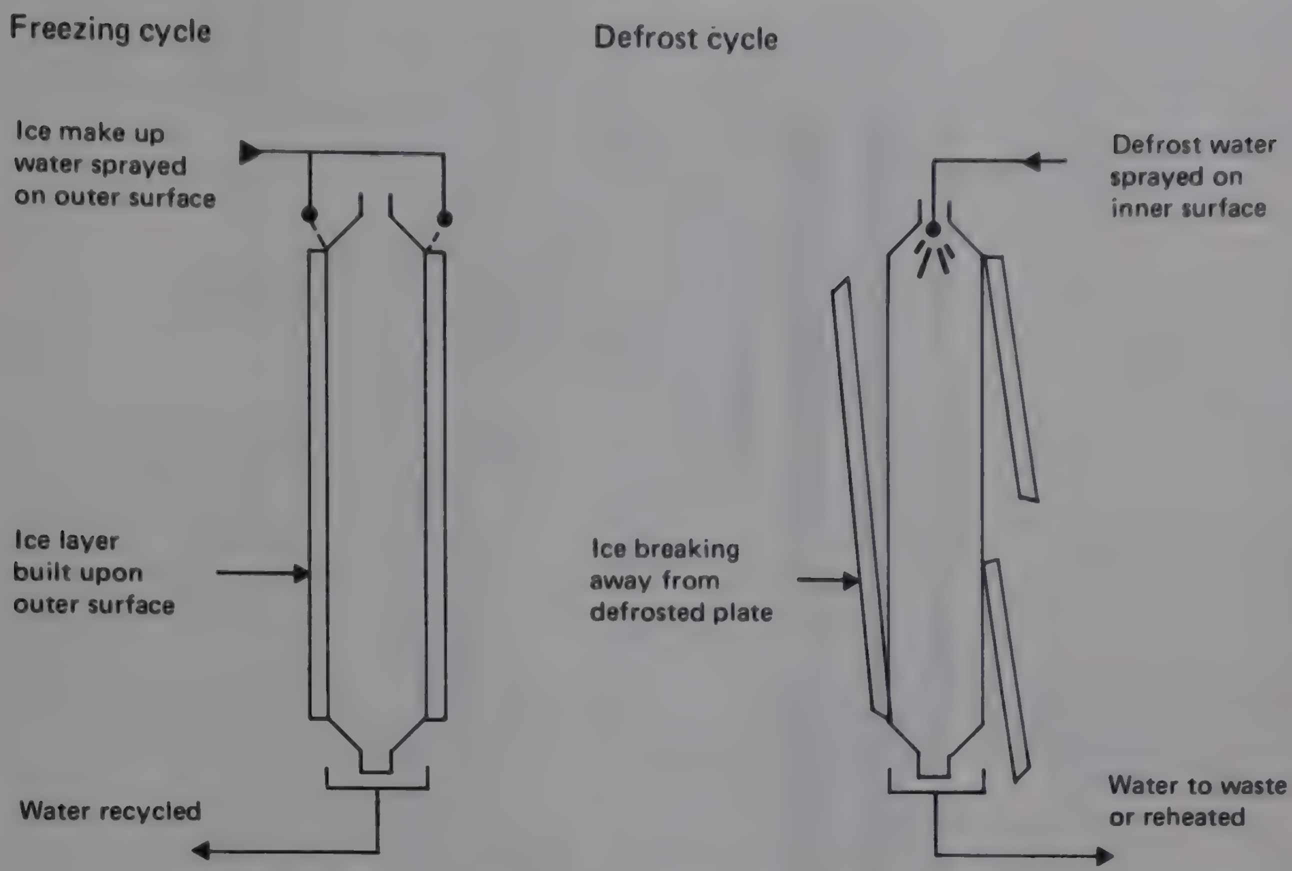
Source: Redrawn from Torry Research Station (1975) Torry Advisory Note No 68.

automatically turns the cans over so that the ice is released and then lifts them up again so that they are ready for filling.

Rapid block ice plants

In this type of plant, the refrigerant passes through tubes which dip into a tank of water, the ice forms round the tubes and fuses into a block. The blocks thus have a hollow core when removed from the tubes by defrosting; rapid block ice plants

Figure 9
Plate ice maker



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1974) FAO Fisheries Report (59 revision 1).

require much less space than ordinary block ice plants, but these have never become very popular.

Flake ice plants (see Figure 8)

A thin sheet of ice, 2 to 3 mm thick, is formed by spraying water on to a refrigerated drum; it is scraped off to form dry sub-cooled flakes. In some models, the drum is rotated; in others, the scraper or knife is rotated; in most designs, the drum is vertical. Flake ice production is continuous and automatic, ice is formed within a few moments of starting up the machine, which can be adjusted so that the thickness of the ice produced can be varied. The ice leaving the drum is cooled below 0°C (subcooled) and is stored in a refrigerated silo, usually immediately below the ice-making machine. This type of ice is ready for use immediately it leaves the refrigerated surface. It is important that the ice is kept subcooled; if it is not, then regelation can occur so that the ice forms a solid mass which is very difficult to handle. In many ports, flake ice machines are now mounted on the quayside so that ice can be shot straight into fishing boats without handling.

Plate ice plants (see Figure 9)

In plate ice machines, the ice is formed on the outer surface of vertical plates and is released, when the required thickness has been attained, by running water on to the inner surface to defrost it. Multiple plates are arranged to form the machine and often these are self-contained units with the refrigerating machinery below the icemaker. The sheets of ice, usually between 10 and 12 mm in thickness, break as they drop from the plates but the pieces are too large for normal use and a simple icebreaker is fitted to reduce the ice pieces to more useable size. The operation is fully automated.

Tube icemakers (see Figure 10)

Ice is formed on the inner surface of a vertical tube as hollow cylinders, 50 mm across with a wall thickness of 10 to 12 mm. The refrigerant surrounds the outer surface of the tubes. The ice is released by a hot gas defrost process and as it drops

than about 3 days' production for it is likely that problems with regelation would be experienced. Ice stores may be simple insulated bins or large refrigerated silos or bins with automatic loading, unloading and weighing.

Silo storage

Silos are generally used only for storing free-flowing, subcooled ice such as flake ice. They must have an independent refrigeration system. Silo storage is too expensive for small quantities and is best suited for 40 to 100 tonnes (see Figure 11).

Ice is removed from the bottom of the silo, flow being assisted by an agitator. There should also be a device to scrape the ice from the walls of the silo which would otherwise build up, leaving only the core free-flowing.

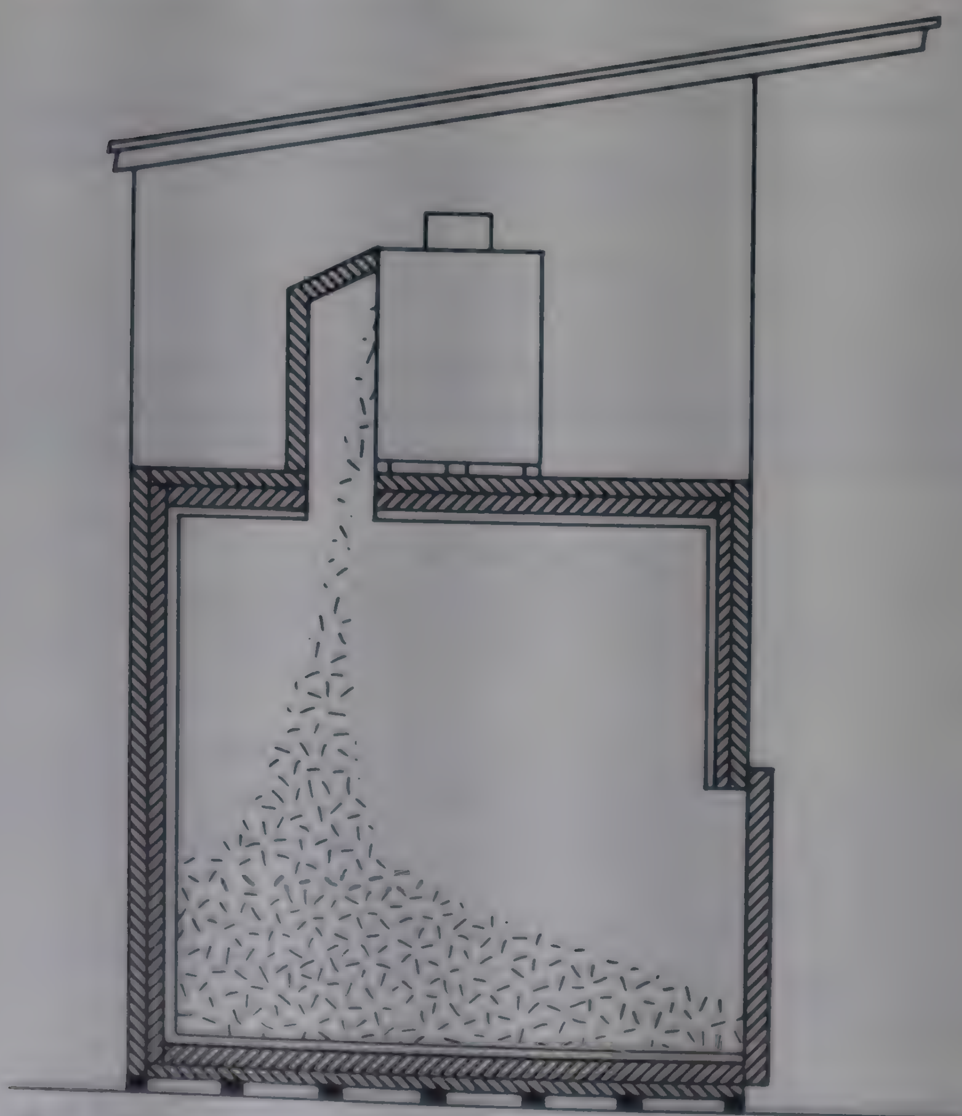
Bin storage

Bins can be of any size from about half a tonne to 1 000 tonnes or more and they are used for storing fragmented ice. Such stores are not always refrigerated in temperate countries but in the tropics it is advisable that both refrigeration and good insulation should be provided.

The bin may be a very simple box; for larger bins (see Figures 12 and 13), the ice plant can be mounted on top so that the bin is filled by gravity. The design of these bins must allow for:

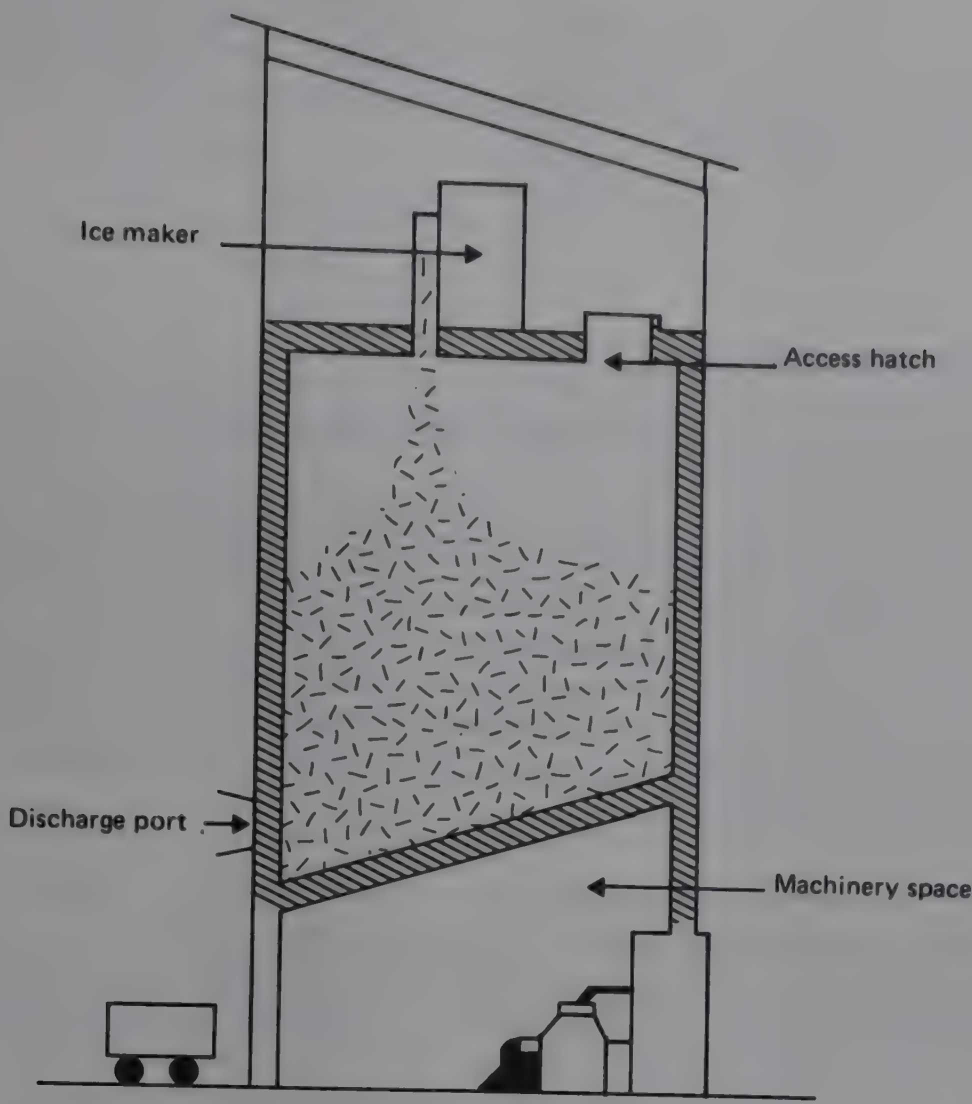
- easy discharge of the ice
- older ice to be removed before the freshly made ice
- access for dislodging any ice which becomes compacted.

Figure 12
Small ice store for 5–15 tonnes



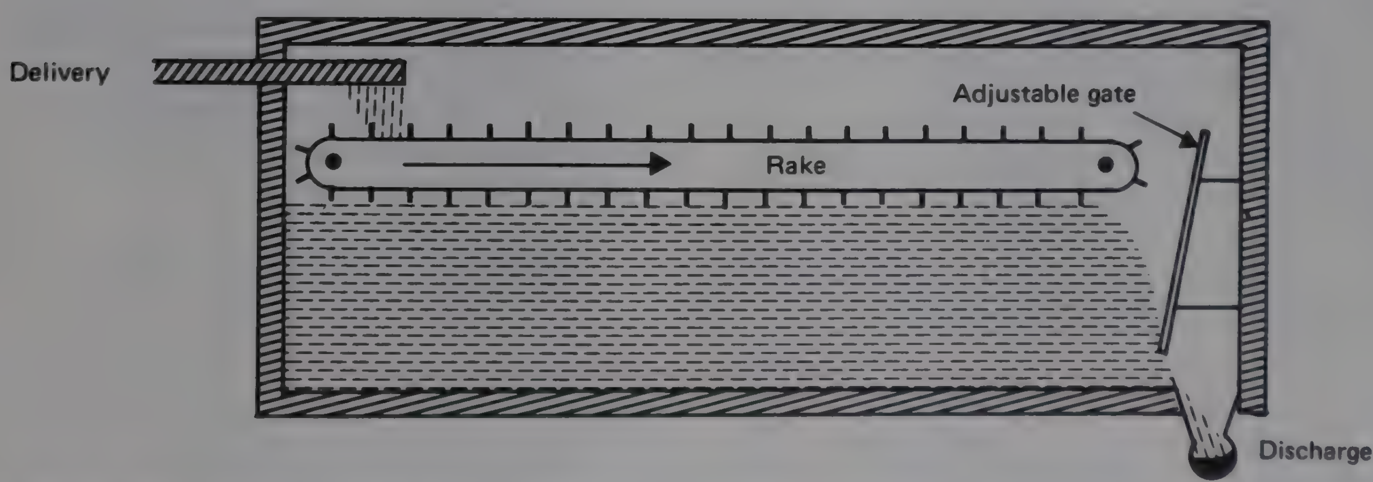
Source: Redrawn from Torry Research Station (1975) Torry Advisory Note No 68.

Figure 13
Bin ice store



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1974) FAO Fisheries Report (59 revision 1).

Figure 14
Large bin ice store with rake discharge system



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1974) FAO Fisheries Report (59 revision 1).

The problem of compacting cannot be always solved by raking, shovelling or the use of moveable screw conveyors. It is, therefore, necessary to clear the bin periodically. The depth of ice in a bin must be limited to 5 m to avoid the fusion of ice under pressure. For bins of more than 50 tonnes capacity, a large floor area becomes necessary, the ice must be distributed evenly and some form of mechanical harvesting is needed (see Figure 14).

Block ice storage

Block ice is usually stored in block form in a refrigerated room. Refrigeration is, however, not essential. It is difficult to stack blocks, particularly the larger ones, because of their shape and weight; moreover, if the store is held below 0° C, any blocks which are touching will freeze together. Some of these problems can be partially overcome by employing dunnaging between layers of blocks but, even so, a relatively large floor is required.

PLANNING FOR ICE MANUFACTURE

Ice manufacture requires a suitable site and suitable supplies of water and power.

The first decision to be made is whether block ice or small ice should be made. The overriding consideration here is whether the ice will have to be transported for long distances or not. Whether or not ice must be carried a long way, a block ice plant is to be preferred since losses from melting will be much less than with small ice. In most other cases, nowadays, a small ice plant is to be preferred because the plants are compact, are fully automatic, and produce ice in a ready-to-use form within a short time of switching on. Flake ice is more commonly used in the fishing industry than any other form of small ice.

The second decision concerns the size of plant and store needed. Where the ice is to be used in a single integrated operation, this decision may be easy. It may be based, for instance, on: the number of vessels fishing for the owner; their length and size; or upon the number of lorries used and the length of trip which they make. In other cases, where a plant is to cater for the entire needs of a fishing port, similar considerations may be applied or the size of plant may be based upon the tonnage of fish to be iced. In tropical countries where ice is used in the fishing boats and also to transport fish up-country, it is usually considered that 3 tonnes of ice are needed for each tonne of fish landed. The possibility of sales to other users, e.g., for poultry chilling, milk plants or restaurants should not be neglected.

Site

The plant should be located where the ice is required or, if this is not possible, so as to keep the transport requirements to a minimum. Moving ice is always expensive. Transporting it in open trucks under tropical conditions can result in losses as high as 50 per cent. Where ice is needed in the boats, ice-making facilities should, if possible, be sited at the quayside so that no handling of ice is needed. Where ice is needed in a processing plant, both a long-term store and a ready-use locker store may be provided.

The table below gives some typical figures for the floor space requirements for a number of types of icemaker:

Type of icemaker	Capacity per 24 hours	Floor space (m^2)	Height (m)
Block ice	50	190	5.0
Rapid block ice	50	30	3.5
Tube ice	50	3.3	6.6
Flake ice	50	2.7	3.7

These requirements are for the icemaker only; refrigeration machinery and handling and storage space are usually greater than this, particularly for small ice plants where the icemaker requires little space.

Storage should usually be provided for at least twice the daily production but, with small ice, should not be more than four or five times the daily production or problems would be encountered with regelation. Storage requirements for different

types of ice vary in relation to their density. The storage requirements for various types of ice are given in the table below:

Type of ice	Space requirements (m^3/t)
Flake	2.2 – 2.3
Tube	1.6 – 2.0
Crushed block	1.4 – 1.5
Plate	1.7 – 1.8

Power

The energy required to produce one tonne of ice varies with the type of plant and the operating conditions. Plants that have a low temperature in the ice plant, e.g., flake ice plants, have a higher energy consumption than others. It is always more expensive to operate a plant in the tropics than in temperate climates. Typical energy consumptions in kWh per tonne of ice produced are:

Type of ice	Temperate area	Tropical area
Flake ice	50–60	70–85
Tube ice	40–50	55–70
Block ice	40–50	55–70

These figures apply to the icemaker and refrigeration machinery only. There may well be additional requirements for conveyors, ice crushers etc. The peak power demand is between 1.5 to 3.8 kWh (2 and 5 hp) for every tonne made each day.

Water

Ice must be made from water that is fit for drinking. This may be obtained from a town supply or from a bore hole. Where there is any doubt at all about the bacteriological quality of the water, it may be necessary to treat this on the site.

Although air cooled condensers may be used for small plants most commercial plants use either evaporative condensers or shell and tube condensers with a cooling tower. Such systems need only one half of a tonne of cooling water per tonne of ice produced. Where the water is run to waste, shell and tube condensers operated at high temperatures use much more water than if operated at low temperatures, as is illustrated in the table below:

Water temperature (°C)	Tonnes of water used per tonne of ice produced
10	15
15	25
20	40
25	60
30	125

Chilling: the use of ice

Chilling is an extremely effective way of reducing spoilage if fish are chilled quickly and kept chilled and also handled carefully and hygienically. The objective in chilling is to cool the fish as quickly as possible to as low a temperature as possible without freezing them. Chilling can never prevent spoilage but, in general terms, the colder the fish are, the greater the reduction in bacterial and enzymic action. To chill fish, they must be surrounded by a medium which is colder than the fish themselves. The medium could be liquid, solid, or gaseous but, of the alternatives that could be used, we will see that ice has much in its favour.

ICE: AN IDEAL COOLING MEDIUM

Ice is an ideal cooling medium. It has a very large cooling capacity for a given weight or volume, it is harmless, comparatively cheap and can cool the fish quickly through intimate contact with the fish. For effective chilling, the ice must be allowed to melt and, furthermore, the melting ice also keeps the fish moist and glossy.

Ice acts as its own thermostat and, since about 80 per cent of the total weight of fish is water, the fish are maintained at a temperature slightly above that at which they would begin to freeze. Another advantage of ice is that it can be fairly easily transported; it is a portable 'cooling method'. Transportation, however, will increase the cost of the ice and, unless it is well insulated during transport, it will melt. Of the two basic types of ice which are made (block ice and 'small ice'), block ice melts less quickly and is therefore preferred in a number of situations, particularly when long distances are involved. Block ice does, however, have to be crushed by hand or by machine and the resultant pieces of ice are less uniform in structure and size than the small ice and, because of the irregularities in size and shape, can damage the fish and will not make such good contact with the fish.

Ice is comparatively cheap, i.e., it is cheap in comparison to other ways of chilling. However, in many tropical countries ice is still very expensive.

PROPERTIES OF ICE

We know that water freezes at 0°C but you may not be familiar with the physical properties of ice and the technical terms involved, which are important in understanding why ice is such a good cooling agent.

A quantity of heat has to be removed from water to turn it into ice and the same amount has to be added to the ice to turn it back to water. The heat required to change from a solid to a liquid is known as the latent heat; 1 kg of ice requires 80 kilocalories (kcal) of heat to melt it. This figure of 80 kcal/kg is known as the latent heat of fusion. It is this property of requiring a large amount of heat to melt ice that makes it such a good cooling agent.

One kcal is the amount of heat required to raise the temperature of 1 kg water by 1°C. More heat is required to warm water than almost any other substance. This capacity of substances to hold heat, when compared to water, is known as the specific heat. This specific heat of water is 1, for other substances it is less than 1, e.g.;

Ice	– about 0.5
Wet fish	– about 0.96 (usually taken as 1)
Frozen fish	– about 0.4
Air	– about 0.25
Most metals	– about 0.1

Specific heat can be used to discover how much heat has to be removed to cool a substance, e.g.:

Heat to be removed = weight of substance x temperature change x the specific heat,

To cool 60 kg ice from – 5 to –10°C requires the removal of:

$$60 \times [-5-(-10)]\,^{\circ}\mathrm{C} \times 0.5 \text{ (sp. heat of ice)} = 150 \text{ kcal}$$

We can now calculate how much ice is needed theoretically to cool a given weight of fish:

If we want to cool 10 kg fish from 25 to 0°C, we would need to remove $10 \times 25 \times 1 = 250$ kcal.

But when ice melts it adsorbs 80 kcal/kg.

Thus the weight of ice required $= \frac{250}{80} = 3.12$ kg.

This is strictly a theoretical calculation; at the end of the cooling process there would be no ice left to keep the fish cool. It does not take into consideration the following factors:

- That ice is also melted by the surrounding air; thus a lot of ice is lost, particularly at high ambient temperatures, unless the fish and ice are protected from the ambient heat, preferably with an insulating material.
- How the fish are packed in ice.
- The length of time that the fish needs to be kept chilled once cooled.
- How quickly the fish are chilled.

Although it is possible to calculate how much ice is required to chill the fish and keep them cool, the calculations are fairly complex and, of course, would not be carried out in practice. What is required is a rule-of-thumb-guide. For initial chilling of the fish in the tropics, a ratio of a least one part of ice to one part of fish should normally be used. More ice should be added as required: sometimes fish will be completely re-iced at an appropriate stage in their handling. A successful icing regime is one in which, by the end of the voyage or journey or when the fish is required for further processing, the fish are chilled and there is a little ice still present.

Before we look at the actual use of ice, it would be helpful to have an idea of the storage life that we can expect from fish when they are held in ice.

Storage life in this context means the length of time the fish will keep in an edible condition using ice as a preservation technique. A considerable amount of experimental work has been carried out on the spoilage of temperate and coldwater marine species of commercial importance in Europe and North America. Much of this has concentrated on a few species, such as cod, haddock, hake, herring and mackerel. In the laboratory situation, ice storage trials are usually made under ideal conditions. This will give an idea of the potential shelf life of the particular fish in

question. However most laboratory experiments use more ice than will probably be used commercially and the fish are held surrounded by ice throughout their storage period.

It is generally accepted that storage life of cod in ice is in the region of 14 days. The table below gives the shelf life of various species of fish, from both marine and freshwater, tropical and temperate waters.

Fish	Length of storage in days
Temperate marine	
Cod	12–15
Haddock	12–15
Whiting	9–12
Hake	8–10
Herring	2–5 or 6
Mackerel	7–9
Redfish	13–15
Temperate freshwater	
Yellow walleye	20
White fish	18
Trout	10
Channel catfish	12
Tropical marine	
Snapper (Brazil)	11–16
Red snapper (Seychelles)	20
Purple headed emporer (Bahrain)	15
Grouper	28
Spanish mackerel	11
Chub mackerel	18
Tuna	29
Bonga	20
Tropical freshwater	
Tilapia	22–28
Mrigal carp	35
Catfish (Amazon)	12–16
Nile perch	20
Lung fish	25

The number and variety of different species encountered in the tropics precludes an intensive study of any one species and it was reported recently that workers throughout the world have studied the storage life in ice of more than 70 different tropical species. Unfortunately, most of the work is done on a one-off basis with little confirmation of results and a great variety of different ice storage conditions. This situation makes direct comparison difficult and makes it almost impossible to come to firm conclusions in general terms about the spoilage of tropical fish in ice. However, it appears that:

1. Freshwater fish have a longer shelf life on ice than marine species.
2. Tropical fish keep longer than temperate or coldwater species in ice.
3. Non-fatty fish keep longer than fatty species.

There are no clear cut reasons as to why these differences might exist, although various theories have been put forward which are as follows:

1. Freshwater fish possibly contain in their flesh an antibacterial substance that is not found in marine fish and which inhibits the invasion of flesh by spoilage bacteria. In addition, it seems that most freshwater fish do not contain a substance called trimethylamine oxide (TMAO) which is present in marine fish. TMAO breaks down after death, in marine fish, into trimethylamine which produces ammonia-like odours and flavours. Freshwater fish do not produce ammonia-like odours during ice storage and may, therefore, be considered of better quality than marine fish after the same length of storage.
2. The apparent difference between tropical and coldwater species during ice storage is often explained by consideration of the normal temperature of the environment in which the fish live. The bacterial and enzymic systems of coldwater species are adapted to function most efficiently at lower temperatures than

tropical fish. When the enzymes and the bacterial flora are lowered to the temperature of melting ice (0°C), the temperature drop is much greater with tropical fish than with those from temperate and cold waters. It has been suggested that this larger temperature drop would cause more of a shock to the enzymes and bacteria in tropical fish and would explain their longer shelf life.

3. In general terms, the higher the fat content of fish flesh, the softer and more delicate is the texture and structure of the fish. For this reason, fatty fish tend to break down physically much more quickly than non-fatty fish during storage.

USING ICE AT SEA

The use of ice on board fishing vessels is common practice these days in many commercial fisheries where fishing voyages are of several days or more and fish must be kept in good condition until landing. In the small boat canoe-type fisheries in many parts of the world, it is not practicable for ice to be taken to sea for a number of reasons. The main reason is that the vessel may be too small to carry ice. It may also not be possible for the fishermen to recover the cost of ice through higher prices charged to the trader or consumer. Where the fisherman is at sea for only a short time, the application of ice immediately on capture of the fish may not be necessary.

The fish room

Commercial fishing vessels which store their catch on ice almost invariably have a hold in which fish are stored below the working deck. This hold is known as a fish room.

Fish rooms should be designed so that they are easy to clean and keep clean; all fitments must be strong and corrosion resistant and there must be adequate drainage from the fish room so that ice melt-water can drain away into what is known as the slush well. In order to make the best use of ice, it is important that the fish room is well insulated. The fish room often has a bulkhead between it and the engine room and there are often large heat gains into the hold through this particular bulkhead. In tropical climates, the warm seas and high ambient temperatures make adequate insulation particularly important. The amount of insulation is obviously variable, depending on the temperatures of the seas, the amount and length of fishing voyages and a number of other factors; these must be worked out in detail before any designs are put forward for a new fishing boat. We will be talking at a later stage about insulation regarding cold storage facilities and we will consider the insulation of the hold at that stage. Another important item which must be considered is the lining for the fish room which should ideally have the following characteristics:

1. It should be watertight.
2. It should be hard and smooth-surfaced, so that it can be easily cleaned, and it should not contain cracks and crevices that will harbour dirt and bacteria.
3. It should be robust and able to withstand blows inflicted by ice axes, shovels and pound boards etc.
4. It should be light in colour.
5. It must not contaminate the fish.
6. It should not be corroded by fish oil, ammonia, brine etc.
7. It should be light in weight.

In addition to the insulation of the fish room, which acts as a barrier to heat penetration, it is recommended that, with all methods used to store fish, a layer of ice at least 15 cm thick be applied to the sides, bottom and bulkheads of the fish room as an additional barrier to heat gain. No fish should be in direct contact with the fish room sides.

Stowage methods

There are three methods of storing fish in ice on fishing vessels.

1. Bulking. The fish room is divided into sections using pound boards supported by stanchions. The resultant pounds measure approximately 1.5 m^2 x 0.7 m high. A layer of ice at least 5 cm thick is spread over the bottom of the pound followed by a layer of fish. Ice is then spread over the fish and around the edges so that the fish are not in direct contact with the sides of the pound. Further layers of fish and ice are added until a depth of about 45 cm ice and fish is achieved, with a layer of 5 cm of ice at the top. A horizontal pound board is now placed over the section. The pound board must be supported by the stanchion structures, not by the fish and ice in the lower compartment. More fish and ice are added in the same way, again to a depth of 45 cm. The operation is repeated until the pound is full. Pound boards and stanchions must be kept clean and out of direct contact with the fish.

2. Shelving. The fish room is divided into sections as it is for bulking but this time removable shelves spaced at about 23 cm are used for holding the fish. The lowest shelf is covered with a layer of at least 5 cm of ice. Fish are placed in rows on the ice and more ice is used to cover the fish to about 5 cm. Only one layer of fish is to be put on to each shelf. Shelves must be supported by stanchions, not by the fish and ice below.

3. Boxing. Fish boxes come in a variety of sizes and materials. Ideally, a box should:

1. Be strong and robust.
2. Be able to be stacked so that the weight of the top boxes are taken by the boxes below, *not* by the fish in the box below.
3. Be able to nest to save on stowage space when empty.
4. Be easily cleaned and, if necessary, sterilised.
5. Allow ice melt-water to flow away outside the box below and not through it on to the fish in the lower box.
6. Have good thermal insulation.

There are a number of designs and sizes of fish boxes made in plastics and aluminium which fulfil many of the above requirements and, furthermore, are light and easy to handle. As yet, however, no manufacturer has designed a box which will stack (point 2), nest (point 3) and allow the ice melt-water to flow away outside the box (point 5). These plastic and aluminium boxes are replacing the older styles of wooden boxes which tend to be difficult to keep clean and do not last as long.

Fish boxes should be used as follows:

A layer of ice 5 cm thick should be placed in the bottom of the box, followed by a layer of fish. A thin layer of ice follows, interlacing fish and ice,until the box is almost full. The ice should be placed around the sides of the box as well as amongst the fish and the top layer of fish should be covered with at least 5 cm of ice. The box must not be overfilled. This prevents crushing the fish when the boxes are stacked into the fish room. When boxing fish, the fish room has no internal pounds or stanchions as in the bulking and shelving methods. There may, however, be restraining bars and straps to prevent stacks of fish boxes falling over.

Bulking, shelving, or boxing?

There are various factors to be borne in mind when choosing which method of stowage of fish at sea to use.

Bulking

1. Of the three methods, bulking is the most economical on space.
2. Fish can be subjected to physical damage through pressure of fish above and pressure of lumps of ice.
3. In general, bulked fish will be of poorer quality than shelved or boxed fish after the same length of time.
4. Mixing of different catches and 'ages' of fish during bulking can be a problem.
5. Fish are often subjected to rough handling during stowage and discharge.

Shelving

1. Of the three methods, shelving is usually the least economical on space.
2. Fish are not subjected to physical damage.
3. If well iced on top, fish are of better or at least equal quality to bulked fish.
4. The method is very labour-intensive.
5. Fish can be separated easily into different catches.

Boxing

1. Boxing is intermediate between shelving and bulking in terms of space requirements.
2. Fish can be separated into size, species and age and kept separate throughout distribution.
3. Handling is kept to a minimum.
4. With good boxing practice, fish will not be damaged physically.

Refrigerated fish rooms

Some fish rooms not only have insulation but also have refrigeration facilities. This refrigeration is usually in the form of cooled grids and pipes on the roof of the fish room. It is important to get the maximum cooling effect from the ice that is allowed to melt. For this reason the temperature in the fish room should not fall below 0°C. In order to prevent melting of ice, it is common practice for refrigeration to be used only before fishing starts when the vessel is carrying ice alone. Under these circumstances, the temperature can be below 0°C.

Insulated boxes

In an increasing number of small boat fisheries, insulated boxes are used to carry ice to sea, and for storing ice and fish, when fishing occupies only a short period. The size of the boxes depends on the size of the boat and the amount of fish normally caught in a day's fishing. The ambient temperature will govern the amount of insulation required in the box, though about 10–15 cm of expanded polystyrene is common. Insulated boxes for small fishing boats can often be made locally at small cost.

Chilling: some alternatives to direct icing

In earlier lectures we have noted that, if fish can be cooled to the temperature of melting ice, their storage life will be much increased. We also noted that placing fish in direct contact with melting ice is the ideal method of cooling.

There are, however, some circumstances in which it is difficult to practise direct icing properly. The most obvious examples of this are where schooling fish are captured in great quantities in a short time. The great catches of herring formerly caught by driftnet in the North Sea were never iced — the quantities of fish taken in one night were enormous and it was impracticable to ice the fish as they were taken from the net. Similarly, it is never possible to ice the vast quantities of anchovies, mackerel, sardines or tuna taken by purse seining. Nor can the crews of trolling vessels spare time to ice the catch since the lines must be tended constantly. In all these fisheries, it is now common practice to stow the catch in seawater which has been cooled to near the temperature of melting ice.

REFRIGERATED SEAWATER (RSW)

Seawater has a salt content of around 30—35 parts per thousand (3—3½ per cent). At 3½ per cent salt, seawater has a freezing point of about −2°C. Thus, if seawater is refrigerated, it is possible to reduce the temperature so that a storage temperature of −1°C can be achieved. The most important advantage of refrigerated seawater (RSW) over icing is the ease of handling and stowage on board, with a resultant saving of labour. In a purse seiner, for instance, the fish can be brailed from the net direct into a tank and brailed out of the tank at the landing point. Pumping systems have been developed for unloading fish as large as 10 kg each at a rate of more than 25 tonnes/hour. In the most sophisticated systems the vessel can be equipped with a pump which pumps the fish out of the sea into holding tanks and the same pumps can be used for unloading. Pumping has the advantage that the RSW storage can be extended to the fish after they are put ashore, in the same water, and without any significant increase in temperature.

CHILLED SEAWATER (CSW)

It is also possible to cool seawater by mixing ice with it. These systems are usually referred to as chilled seawater (CSW) and can be extremely simple. There are also cases where it is advantageous to mix the two systems so that some cooling is supplied by refrigeration and some by the use of ice.

For any system, the recommended ratio of fish to seawater is between 3:1 to 4:1. In RSW systems, it is usually necessary to provide pumped circulation of the water to ensure even mixing. This is sometimes done with CSW systems but, with these, pumping is usually unnecessary, the motion of the vessel providing adequate mixing.

A rough calculation of the amount of ice needed to provide adequate cooling in a CSW system can be made quite easily:

Calculation

Suppose you want to cool *8 tonnes of fish (8 000 kg) from 24 to $-1°C$* and decide to use a 4:1 ratio of fish to seawater. The mixture of seawater and fish would weigh 10 tonnes (10 000 kg) and the amount of heat to be removed would be:

10 000 x 25 x 1 (taking 1 to be the specific heat of both fish and water)
= 250 000 kcal.

But when ice melts, it absorbs 80 kcal thus the weight of ice required:

$$\frac{250\ 000}{80} = 3\ 125 \text{ kg of ice.}$$

Thus, just over 3 tonnes of ice would be required to provide the initial cooling. This, of course, would only reduce the temperature of the fish and would not be sufficient to maintain the lower temperature. Additional ice would be required to provide against the heat leak which would be expected. The amount of additional ice needed would depend on the adequacy of the insulation of the tank or fish room, the outside ambient temperature, and the duration of the trip.

It is somewhat more difficult to make a calculation for RSW loads and these are best left to competent refrigeration engineers. As a guide, however, it may be noted that if one wished to cool the same 10 tonne mixture of fish and seawater as in the previous example to the same temperature, it would impose a load of some 1 000 megajoules on the refrigeration system. If you needed to remove this amount of heat in about 6 hours, you would have to have a plant with a power requirement of about 12 kW for the compressors.

Chilling in CSW or RSW can be rather faster than chilling in melting ice because of the more intimate contact between the fish and the cooling medium. In practice, however, cooling will *not always be quicker* because there are limitations to the circulation in both systems and, also, there are limitations in the mechanical refrigeration system used in RSW.

It is perhaps obvious that, if a refrigeration system is particularly good, it would be possible to cool fish below the temperature at which they would freeze. This should be avoided because slow freezing results in fish of very poor eating quality. Freezing, however, is impossible in CSW systems, in RSW systems freezing could be avoided by using thermostats and by sensible choice of the size of the compressors provided. If one avoids undue build-up of ice on the refrigerating coils, there should be no problems with freezing.

There is one further problem associated with using cooled seawater for fish stowage: that of salt penetration into the fish. The amount of increase in salt depends on several factors: the size and species of fish; whether they have been gutted or not; the ratio of fish to water; and the length of the storage period.

Gutted fish, or fish which have been cut, will absorb salt at the cut surfaces. With the recommended ratio of fish to seawater of 4:1, and where there is no introduction of seawater after the initial stowage, the amount of salt taken up by the fish cannot exceed 1 per cent by weight. However, a concentration of 1 per cent would be objectionable in many fish products and, in many markets where fresh fish are sold, the housewives would reject such fish. Where fish are to be frozen after landing, any rise in salt concentration would be objectionable since salt can accelerate some of the changes which take place in cold storage and thus decrease the storage life. Even if the fish are to be used for fishmeal manufacture, an increase in salt content is objectionable since this will be proportionately increased approximately five times when the meal is made.

In other cases, there is no objection to the slight salt uptake. Particular examples are where fish such as salmon, tuna and shrimp are to be canned; if the fish will be salted, either as a preliminary to drying or smoking, there is of course no objection, though note may need to be taken of the salt content of fish before processing is attempted.

SOME EXAMPLES OF SEAWATER CHILLING SYSTEMS

Simple CSW systems

Very simple CSW systems have been used by South East Asian purse seiners since the 1930s. The system is said to have been developed where a purse seiner from Pangkor Island in Malaysia returned to port in a leaking condition with a cargo of chub mackerel in excellent state. The seawater had leaked into the cargo of mixed ice and fish, buoyed up the fish and prevented the bruising damage which normally occurs if the small delicate fish are mixed with lumps of ice. Within a very short time, all the boats of the Pangkor fleet were fitted with simple insulated tanks in which a mixture of fish, seawater and ice could be stowed. The tanks were built as an integral part of the vessel in much the same way as the fish hold which had formerly been constructed. Apart from improvements in the insulation, the system is little changed today.

The principles of construction are fairly simple. The hold must obviously be large enough to take the maximum anticipated catch. Thus, if it is expected that 16 tonnes of fish will be caught, one must allow an additional 4 tonnes for water – a total of 20 tonnes – which would occupy a space of just over 20 cubic metres. Cooling 20 tonnes of fish plus water through 25°C requires about 6 tonnes of ice but, even for overnight storage, it would be unwise to put to sea with much less than 10 tonnes of ice. For a longer voyage, more ice must be carried; remembering that one would expect to carry as much ice as the weight of fish to be chilled and kept chilled, one would reasonably expect to carry about 20 tonnes of ice for a normal trip, using CSW, if 20 tonnes of fish plus water were to be kept chilled. Much depends on the efficiency of the insulation used.

The accepted design has been to subdivide the vessel into fixed longitudinal tanks. Obviously at least two fish holds or tanks are required so that ice need not be wasted if only a small catch is taken, the ice being kept separate from the mixture of fish, seawater and ice. When purse seining, it is essential that very large hatches should be fitted so that fish can be brailed straight from the net into the hold. Good insulation, at least 10 cm (4 in) of polystyrene foam or similar material, should be provided on the deck, on the fish room floor and shipside and bulkheads. If there is a bulkhead in the way of the engine room, at least 15 cm (6 in) of insulation should be provided. Thicker insulation would of course reduce the amount of ice required for cooling; unfortunately, it also reduces the amount of space available for fish stowage and, as with any other system, the costs of providing additional insulation must be balanced against the cost of cooling; i.e., the price of ice or of the cost of additional refrigerating machinery. All such tanks should, of course, be perfectly watertight; arrangements should be made for them to be drained into the bilge so that they can be properly cleaned.

One often sees such systems misused: the fish are brailed into the hold, ice is thrown in on top of them, smashing and bruising them, and only then is water admitted, a few bucketfuls being tossed into the mixture. This cannot provide for rapid cooling. Ideally, one should prepare the tank for use by pouring clean water into it and then adding ice so that the water is cooled down before any fish are added. Such perfection is admittedly difficult in fisheries where one cannot begin to guess how much fish is to be taken, even when, for instance, a ring has been made with a purse seine; but it is not too difficult to make some kind of guess, nor is there any difficulty in calculating how many buckets full of water should be used to so many blocks of ice in order to provide proper chilling. One cannot expect fishermen to do this. However, an extension service should be able to provide suitable advice. As in

so many other areas of fish handling and processing, a few hours work with a thermometer will do much to save money and increase profitability.

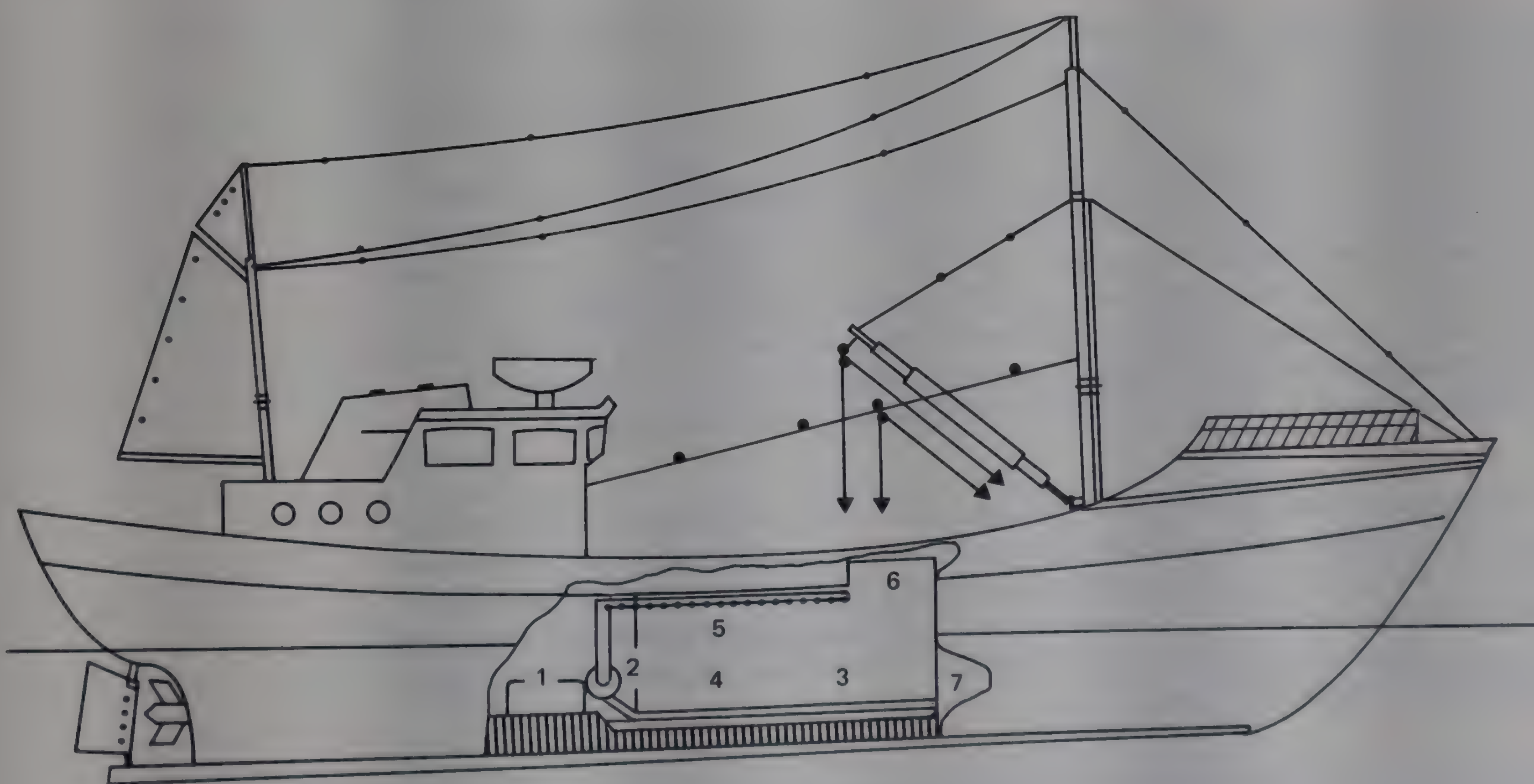
The system should of course be designed so that the stability of the vessel is not affected. This requires primarily that the catch should be kept as low down as possible and, also where possible, the holds should be arranged so that they fill completely with fish, water and ice in order to avoid physical damage due to the motion of the vessel and to reduce aeration of the water. One of the advantages of using CSW should be reduced rancidity of the catch since the amount of oxygen available to oxidise the fat should be less than in an air system.

RSW systems

RSW systems, although more complicated than CSW systems, are not necessarily more expensive to operate. Figure 15 shows a typical European system. Where ice is expensive, it may in fact be cheaper to operate a small compressor than to buy ice. Also, where ice has to be carried considerable distances so that there are excessive losses due to melting, it may also be better to employ a simple RSW system. One must, of course, also bear in mind the fact that any piece of additional mechanical equipment has its hazards in areas where maintenance facilities may be rather poor.

Storage tanks should be watertight and easily cleaned. They must be designed with the stability requirements of the vessel borne in mind. Tanks of aluminium, plastic reinforced with fibre-glass, and steel coated with protective anticorrosive substances have all been used. Tanks constructed in marine plywood have proved satisfactory,

Figure 15
Danish trawler with three RSW tanks installed in the aft hold. Longitudinal section of the centre tank with installations for circulating and cooling the water.



1. Refrigerant compressor.
2. Seawater circulation pump.
3. Evaporation tubes placed in channels in tank bottom.
4. Perforated plates covering the channels through which the sea water enters the tank.
5. Perforated suction pipes through which sea water is removed from the tanks for recirculation.
6. Hatch.
7. Traditional fore-hold.

Source: Redrawn from 'Fishery Products', Edited by Rudolf Kreuzer. Published by arrangement with the Food and Agriculture Organization of the United Nations, © FAO (1974) by Fishery News (Books) Ltd, West Byfleet, Surrey England.

the plywood being installed in two layers with staggered joints and plastic reinforced with fibre-glass or rubber-based paint applied to the inside. In the South East Asian area, tanks have also been constructed out of ordinary hardwood timber and lined with zinc or galvanised iron sheet. Such tanks are cheap but it is not easy to make them leakproof and it is to be expected that rot will be a problem in later years. Although tanks used in cold climates are often used without insulation, this should be provided in any vessel employed in the tropics. The space surrounding the tanks should be insulated but, where tanks lie adjacent to one another, this is not required.

Obviously, it is preferable if the tank volume is divided into several parts so that mixed catches can be sorted and so that fish of different ages need not be mixed. It is also best if the tanks can be filled completely in order to prevent physical damage to the fish and possible aeration of the water. Tanks are usually constructed with a narrow section at the top. This reduces the difficulty of keeping the tanks full.

In very small systems where the tank volume is low, it is not normal practice to provide water circulation. In larger systems, however, circulation must be provided (see Figure 15.) The arrangement must take into account the fact that fish are likely to block the area where water is drawn out. Suction screens, typically of expanded metal with openings of about 2 cm diameter and an area of 0.5 m^2/m^3 of tank, are used to give good circulation, the pump being located outside the tank. It is best to arrange for circulation from the bottom to the top of the tank.

The system is usually started by partially filling the tank with the appropriate amount of water which is then refrigerated, the fish being added last. Spare fish tanks are often used to provide a reserve of chilled water before they are filled with fish but care must be exercised to see that the total amount of water is kept low so that salt penetration is reduced.

Ordinary centrifugal pumps, installed below tank level where this is possible, are used to recirculate water through the tanks. Usually the pump is arranged so that it discharges through the water chiller; sometimes separate pumps are installed for each tank, or one pump may be used to serve a number of tanks in parallel. The pump capacity should be around 25 cm^3/second for each 100 tonnes of fish to be stored. Obviously piping could be a source of bacterial infection and it must be arranged so that it can be kept clean. Galvanised iron piping has commonly been used in the past but plastic piping would be preferred except in places where it might suffer physical damage. The simplest possible valves should be used. All the piping should be arranged so that it can be cleaned by pumping detergent or sanitisers through it and so that the system can be flushed overboard.

The actual water chiller may be a shell and tube heat exchanger or a refrigerated pipe coil. Whatever chiller is used, it should be arranged for easy cleaning because the tank will be left with a mass of blood, slime, scales and pieces of fish in the water after the catch has been brailed out. Both copper and galvanised steel tubing have been used successfully. Copper must, of course, not be used with ammonia because it is readily attacked.

The system should be charged with seawater on the fishing grounds, not in harbour, so that there are few bacteria in the initial load. As soon as the fish have been landed, the system should be cleaned throughout, otherwise slime and other material will dry hard and may prove extremely difficult to clean off. The tanks themselves should be scrubbed out, using clean water from a hose and a suitable detergent. Any material which adheres to the surfaces should be scrubbed off. The piping system should be thoroughly flushed and then cleaned by circulating a cleaning solution. Some users leave a very weak solution of disinfectant in the piping system until just before the tanks are to be filled, the entire system being flushed with clean seawater before the new catch is put in.

Containerised bulk stowage on fishing vessels using CSW

This is a portable tank system developed by the Industrial Development Unit of the British White Fish Authority. The majority of herring are nowadays packed into 30 kg boxes with about 5 kg of ice. This is carried out aboard the catching vessels which are typically from 20 to 25 m length overall. The fish travel about the country in the boxes and 40 hours could elapse between the time they are caught and the time they are processed in a factory. The system described here was developed in order to expedite handling.

It was decided that CSW would be a suitable method since ice is freely available in the fishing ports. A standard aluminium transport container of 2.1 m capacity was selected and modified by providing an insulated outer covering and special filling and discharge arrangements (see Figure 16). The containers are put in the fish room at the start of the voyage. At this time, each of them holds 450 kg of ice. When fishing starts, each container is charged with 500 l seawater and the herring are run directly into the containers through a deck opening. Each container holds 1 350 kg fish. Compressed air is used to provide agitation and ensure that the entire contents are at the same temperature. When the vessel arrives in port the containers are lifted directly on to road vehicles and carried to the processing factory; the vessel can take on new containers at once. At the factory, the container is placed on a tilt unit, when the fish are needed for processing, and the contents fall into a dewatering trough which admits the fish to the production line.

The arrangements of the containers on board is shown in Figure 17. It should be noted that the tanks are stowed on pallets for ease of handling. The system provides fish of better quality than those obtained through traditional icing and offers a number of other advantages over the boxing system. It is much easier for the crew to pack the fish into the containers rather than into boxes and a smaller crew is needed

Figure 16
Insulated aluminium container measuring 2.1m^3.

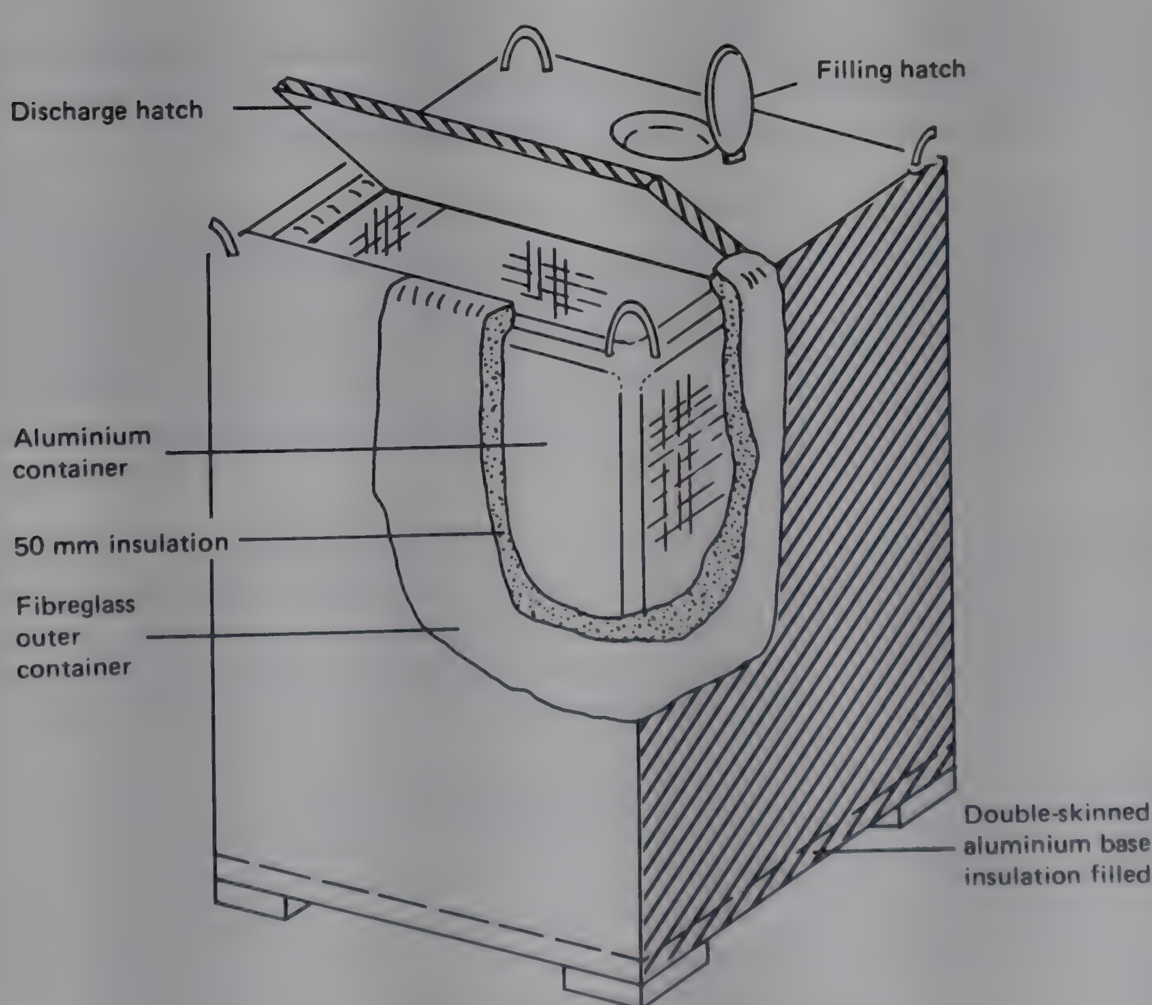


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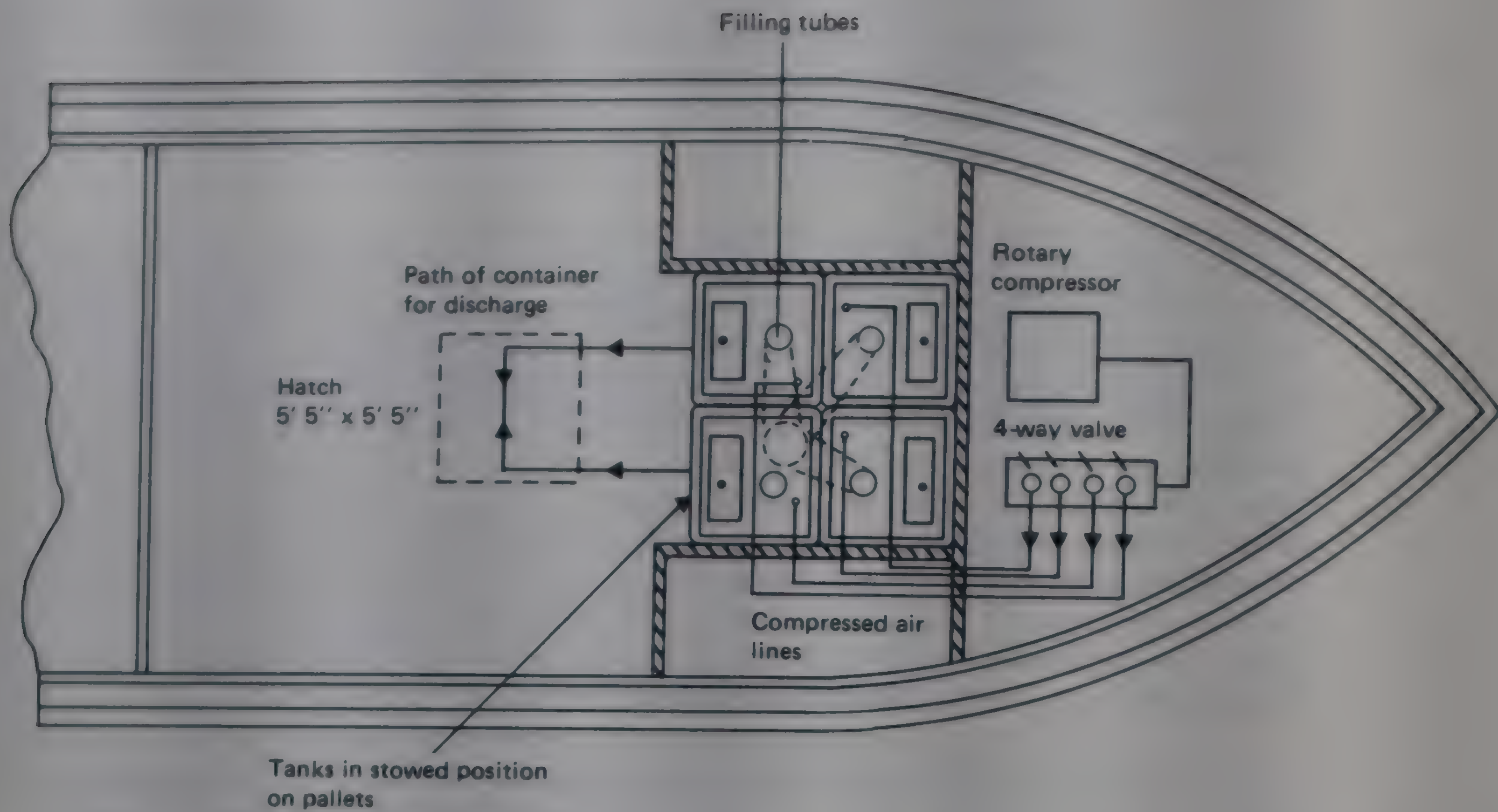
Figure 17
Four-container CSW system, MFV Ajax.



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than when boxing. Handling of the fish is avoided entirely during transport; the containers are easy to handle by crane or fork lift truck. The fish are in an insulated container in an efficient cooling medium and the safe holding time from catching to processing can be accurately predicted.

There is only one major disadvantage, which is that using the containers reduces the carrying capacity of the vessel; in a 25 m herring trawler, the capacity for containers is only about 60 per cent of that for fish stowed in 30 kg boxes.

The most important result from the point of view of the fishing industry has been that herring stored in containers of this type are of much superior quality to herring stowed in conventional ice boxes. Very soft fish, which had a high oil content, were acceptable after a storage period of 87 hours; firmer fish were kept for much longer periods. A limited amount of work has been carried out on the quality of white fish stored in CSW but, whilst holding periods of up to 6 days have given acceptable quality, more work is at present being progressed.

Freezing

We have seen that by using ice and other chilling techniques we can keep fish in a 'fresh' condition for anything from a few days up to four weeks or so depending on the species of the fish. In many situations, it is desirable to be able to keep the fish fresh for longer than a few weeks, e.g. for export to distant countries, to even out supplies because of seasonal variations in catch and when fishing grounds are a long way from port. It is not possible to keep the fish fresh for prolonged periods but it is possible to produce a product which closely resembles fresh fish by using freezing and cold storage.

WHAT IS FREEZING OF FISH?

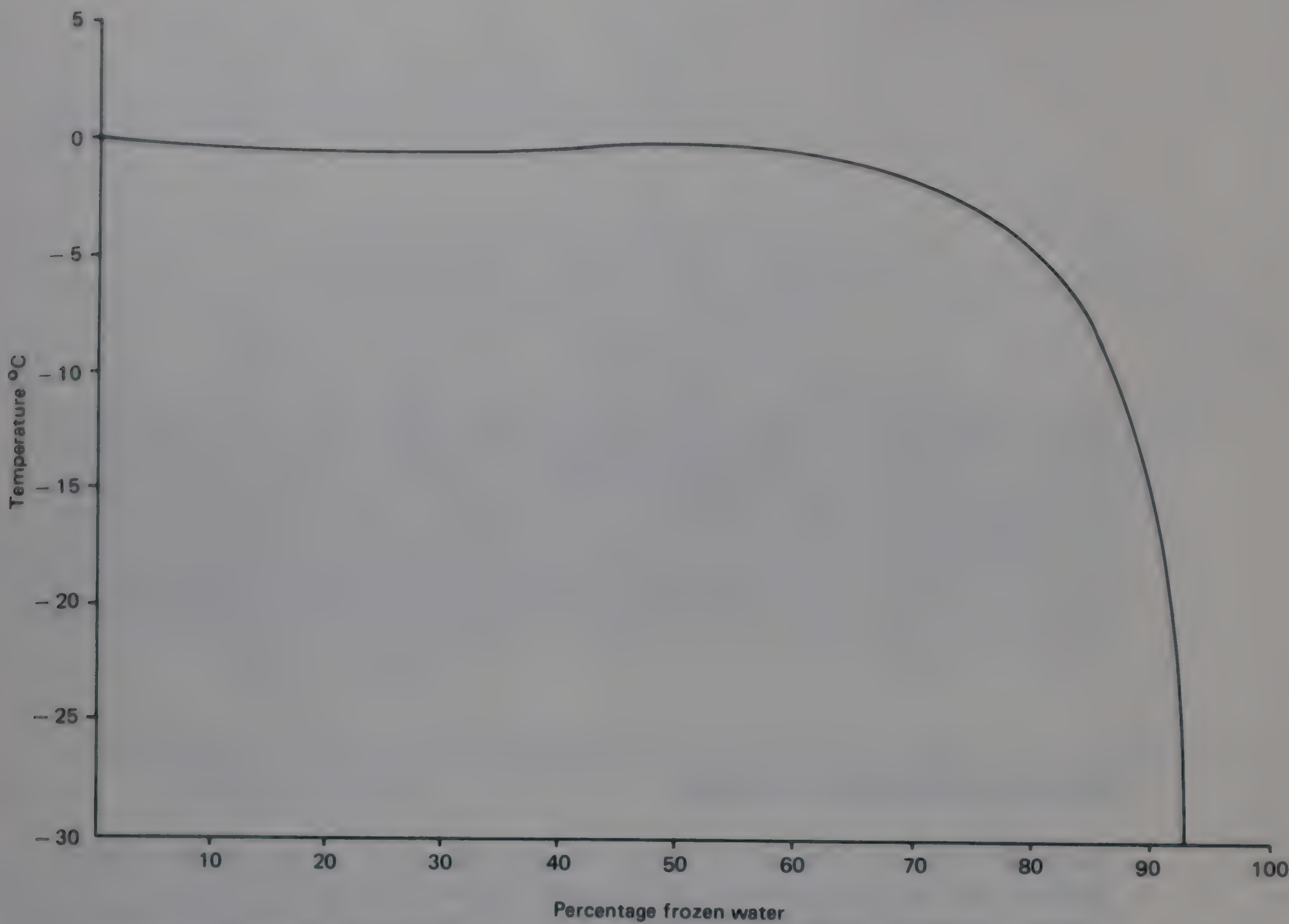
Fresh fish flesh contains approximately 80 per cent water. At normal atmospheric pressure pure water will change from a liquid to a solid (ice) at 0°C i.e., it will freeze. The water in fish flesh contains salts and chemicals which have the effect of lowering the temperature at which the water begins to freeze. The water in fish flesh begins to freeze at about −1°C and, as the temperature drops below −1°C, more water is frozen out and the concentration of salts in the remaining water rises so that its freezing point is lowered further. At −5°C, when it would appear that all the water is frozen, over 20 per cent of the water in fish muscle is still unfrozen. Even at −30°C, approximately 10 per cent of the water remains unfrozen. (See Figure 18.)

In order to change the physical state of a substance from a liquid to a solid, as we are doing when we are freezing fish, energy or latent heat has to be removed from the substance. In order to lower the temperature of 1 g of water by 1°C, at temperatures above 0°C, 1 calorie of heat must be removed; this is known as the specific heat. However, to change water at 0°C to ice at 0°C, 80 calories must be removed for each g of water.

In other words, the specific heat of liquid water is 1 and the latent heat of changing liquid water to ice is 80. The specific heat of ice at temperatures below 0°C is 0.5 which means that to lower the temperature of 1 g ice by 1°C we would need to remove 0.5 calories of heat. For all practical purposes, it is assumed that fish have the same values for specific heat and latent heat as water.

All this means that, if we remove heat from fish at a constant rate, there will be a period whilst the fish is freezing where the temperature of the fish will not drop. This period lasts until approximately 75 per cent of the water is frozen, when the temperature begins to drop again. There are then three stages to freezing fish. During stage 1, the temperature falls fairly rapidly to just below 0°C; during stage 2, the temperature remains fairly constant at about −1°C as the bulk of the water in the fish freezes (this stage is known as the 'thermal arrest' period); and during stage 3, the temperature again drops and most of the remaining water becomes frozen. This 3-stage reduction in temperature during freezing is illustrated in Figure 19.

Figure 18
Percentage of water frozen at different temperatures in fish muscle



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

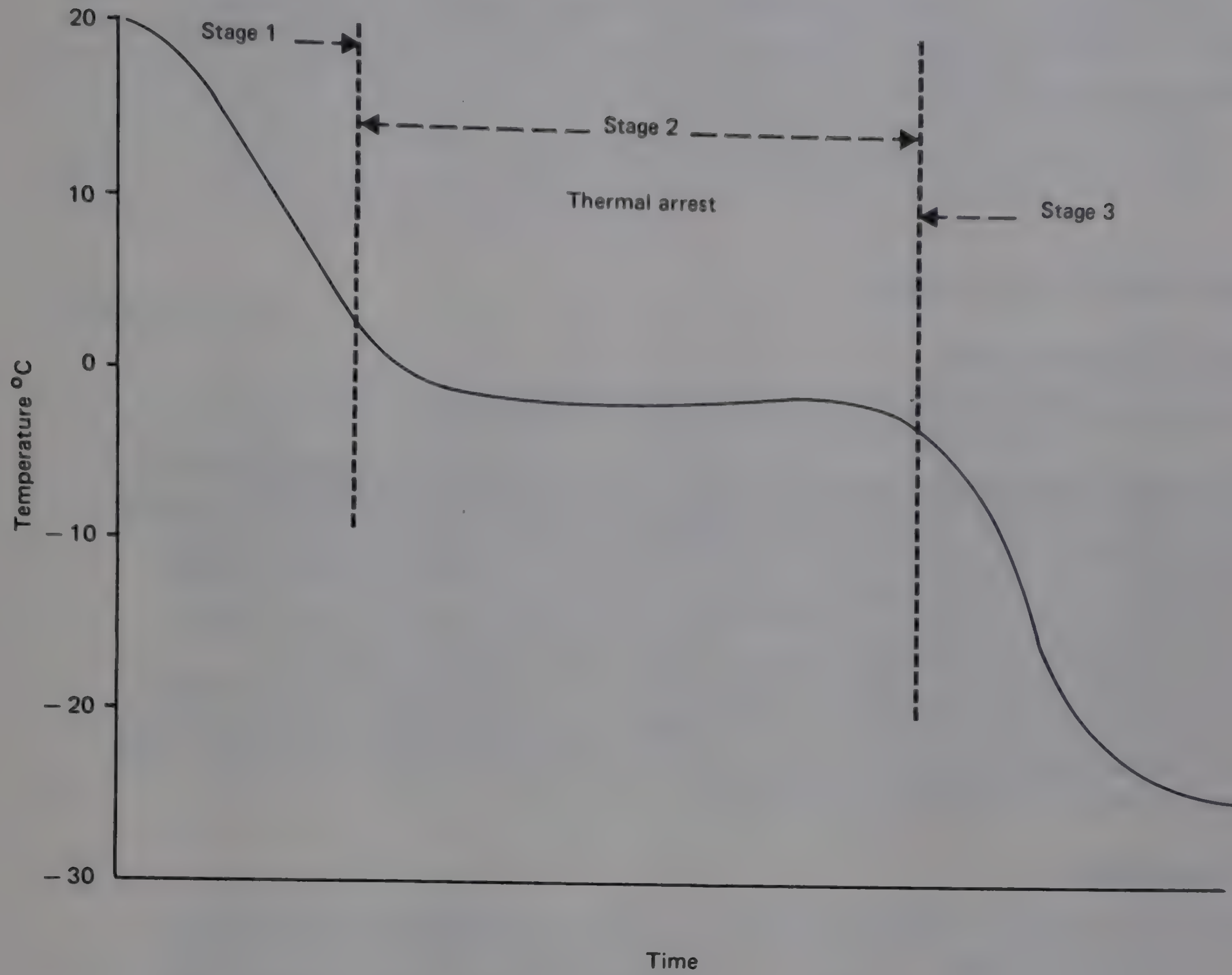
Using simple mathematics we can calculate the amount of energy required to freeze fish. This is most easily demonstrated by making a simple calculation as follows:

> Suppose we have 1 kg fish at 25°C and we wish to freeze it to – 30°C. During stage 1, we need to extract 1 calorie of energy for each g material for each drop of 1°C. In the example we will be lowering the temperature of 1 000 g of fish from 25 to –1°C, i.e. by 26°C. The energy required will be equal to 1 000 x 26 x the specific heat of water (1) = 26 000 calories or 26 kilocalories (kcal).
>
> During stage 2, we need to extract 80 calories of energy for each g material frozen. In the example 1 000 g of fish are to be frozen. The energy required will be equal to 1 000 x the latent heat for freezing water (80) which equals 80 000 calories or 80 kcal.
>
> During stage 3, we need to extract 0.5 calories of energy for each g material for each 1°C drop in temperature. In the example we will be lowering the temperature of 1 000 g fish from –1 to –30°C, i.e. by 29°C. The energy required will be equal to 1 000 x 29 x the specific heat of ice (0.5) = 14 500 calories = 14.5 kcal.

To summarise:

Stage 1	1 000 x 26 x 1 = 26 kcal
Stage 2	1 000 x 80 = 80 kcal
Stage 3	1 000 x 29 x 0.5 = 14.5 kcal

Figure 19
Typical fish freezing curve



Note: Under ideal conditions fish would be frozen to −30°C in 3 hours

Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Adding these three figures gives us 120.5 kcal, i.e. to freeze 1 kg of fish from 25°C to −30°C we require 120.5 kcal of energy.

From the example above it is apparent that more than 50 per cent of the energy extraction during freezing of fish is necessary during stage 2, the thermal arrest period, when little or no drop in temperature is occurring, and this period is a critical one if we are to produce a good frozen product. Ideally, fish should pass through the thermal arrest period as quickly as possible.

There are various reasons for this:

1. Slow freezing produces large ice crystals in the cells of the fish which can be larger than the cells themselves and so break the cell walls.
2. We have already mentioned that, as the water begins to freeze in the flesh, the concentration of salts and chemicals in the remaining water rises. This high concentration of salts and enzymes can cause accelerated autolysis.
3. At temperatures around 0°C, certain types of bacteria are still active and bacterial spoilage can still occur.

Textural changes occur in fish which have been frozen slowly caused by the presence of large ice crystals and denaturation of protein during the accelerated autolysis. In addition, a phenomenon known as 'thaw drip' occurs when slowly frozen fish are thawed. On thawing, the water which was originally bound within the cells is released and considerable loss in weight can occur.

However, from a textural point of view it is unlikely that a highly trained taste panel could detect the difference between fish frozen in 1 hour and those frozen in 8 hours but, once freezing times extend beyond 12 hours, the difference may well become apparent. Freezing times of 24 hours or more will almost certainly result in an inferior product and very long freezing times can result in bacterial spoilage making the fish unfit for consumption.

FREEZING DEFINITIONS

What is quick freezing?

There is no widely accepted definition of quick freezing.

In the UK, quick freezing is defined normally as lowering the temperature of fish from 0 to −5°C (the thermal arrest period) in 2 hours or less, and further reducing the temperature at the end of the freezing period to the recommended storage temperature of −30°C. These two basic requirements for freezing, that the fish should be frozen quickly and then reduced to storage temperature, go together since it is likely that a freezer which can quick-freeze fish also operates at sufficiently low temperatures to ensure that the recommended product storage temperature can be achieved. The recommendation that the fish should be reduced to the intended storage temperature is important and this should be included in all good codes of practice for quick freezing.

Freezing rates

Some freezing codes and recommendations define freezing rate in terms of the thickness of fish frozen in unit time. The freezing rate, however, is always faster near the surface of the fish, where it is in contact with the cooling medium, and slower in the centre. Freezing rates, therefore, are only average rates and do not represent what happens in practice. The table below gives an idea of the terms used in relation to freezing at different rates.

Term used	*Rate of freezing*
Slow freezing	2 mm/hour
Quick freezing	5–30 mm/hour
Rapid freezing	50–100 mm/hour
Ultra rapid freezing	100–1 000 mm/hour

'Sharp' freezing is a term that is often used when people talk of freezing fish but the term has no precise definition and, in practice, sharp freezing is often very slow.

'Deep' freezing is defined by the International Institute of Refrigeration as a process whereby the average temperature of the product is reduced to 0°F (−17.8°C) and then kept at 0°F or lower. The definition does not take into account the rate of freezing and a product that has been deep frozen may not necessarily have been quick frozen before storage.

One exception to the general requirements for quick freezing of fish is frozen tuna. The Japanese product *Shasimi* is based on eating raw tuna. Tuna can be very large fish (up to 60 or 100 kg) and the Japanese market requires whole fish. Japanese fishing vessels catching fish for *Shasimi* operate air blast freezers at −50 to −60°C air temperature. This very low air temperature in the blast freezer overcomes, to some extent, the very poor heat extraction from the centre of such large fish. Even with temperatures of −50 to −60°C, it still takes 24 hours to freeze tuna at the centre. The above requirement for air blast freezing tuna is one special case where general rules for quick freezing are not applied and it should be kept in mind that local requirements for particular products may, in some countries, give rise to other special cases.

Double freezing

'Double freezing' means freezing a product, thawing, or partly thawing it, and re-freezing. This practice is often necessary for production of some frozen fish products made from fish previously frozen and stored in bulk. What must be remembered is that even quick freezing results in quality changes in the fish and double freezing will therefore result in further changes. Only fish that were initially very fresh could therefore be subjected to double freezing and still conform to good quality standards. Fish frozen quickly at sea immediately after catching, for instance, would be suitable for this purpose.

REFERENCES

1. GRAHAM, J. (1977). Freezing in fisheries. *FAO Fisheries Technical Paper* (167), Food and Agriculture Organization of the United Nations, Rome, 83 pp.

2. TORRY RESEARCH STATION (1965). Quick freezing of fish. *Torry Advisory Note No. 27,* Torry Research Station, Aberdeen, 14 pp.

Design of freezing plants

There are now many different types of freezing plant available for freezing fish and the choice will depend on cost, function and feasibility. These factors are necessarily governed by location and the type of product.

There are three methods of freezing fish:

1. *Air blast freezing* by passing a continuous stream of cold air over the fish.
2. *Contact or plate freezing* by placing the fish in direct contact with the freezer plates.
3. *Immersion or spray freezing* by placing the fish in a refrigerated liquid.

AIR BLAST FREEZERS

Theoretical considerations

The main advantage of air blast freezers is their versatility. However, they tend to occupy more space and consume more energy than other types of freezer, for example plate freezers, and, because of their versatility, are often used inefficiently.

Air blast freezing is carried out either as a *continuous process* in which the product moves through the freezer or a *batch process* where the product is stationery. Uniform freezing is achieved only if the temperature and speed of the air over the product is constant:

1. *Air speed.* A faster freezing rate occurs with a faster air speed. However, much energy is expended through convection and, generally, the larger the fan the more expensive it becomes to circulate the air. A compromise between high costs and slow freezing rates is therefore made and this results in an air speed of about 5 m per second. This can be increased to 10 or even 15 m per second in continuous freezers where size is a limiting factor.
2. *Temperature.* Too high a rise in temperature of the refrigerant air as it passes over the product results in reduced freezing rates of the more remote products. An accepted average air temperature rise is between 1 and 3°C. It should be noted, however, that this is an average and, after a plant has just been filled, the temperature rise will be higher.
3. *Air flow.* Uniform air flow is essential for efficient operation and the design of tunnels and fans affects this in the following ways:
   (a) Fans should always be placed before the cooler as the latter evens out air flow due to its resistance.
   (b) Fans should have only a few millimetres clearance from their outer casing to prevent recirculation of the air.
   (c) With a change in direction, baffles should be fitted to guide the air smoothly around corners to provide uniform air flow over the products. These are often adjustable in pitch to allow for differing operating conditions.

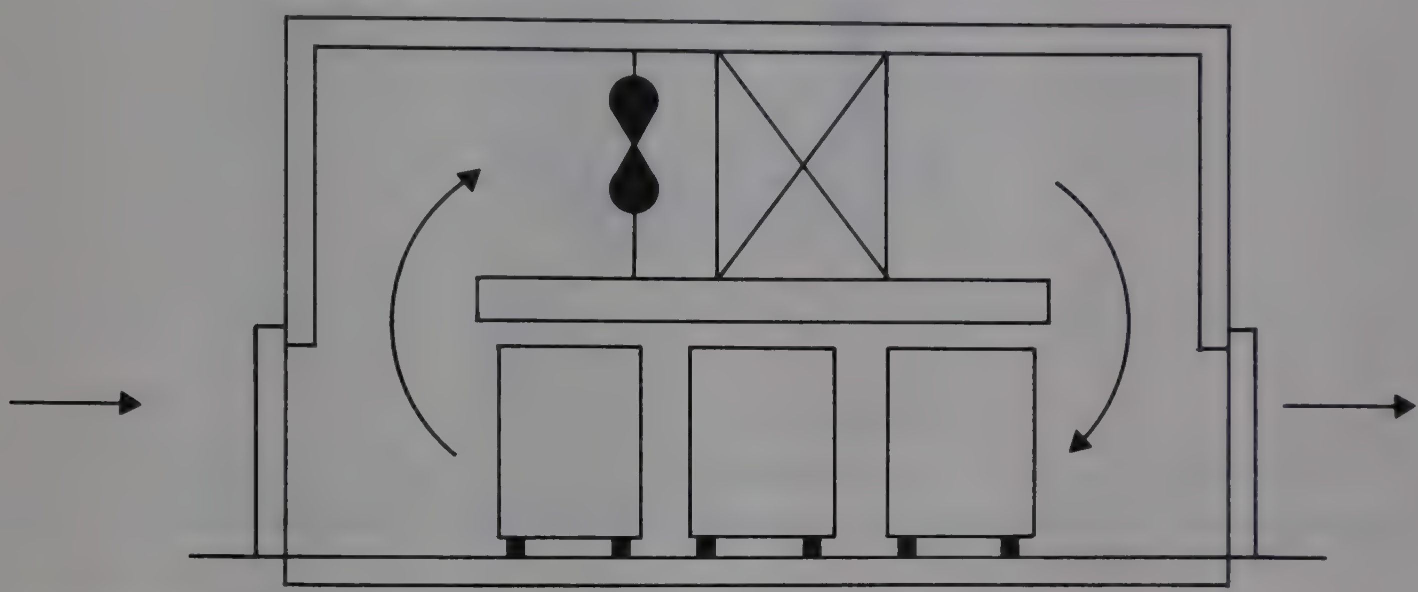
Frosting: In mainly the first stages of freezing, water is lost from the fish and is deposited as frost on the cooler. This restricts the flow of air as it builds up and is usually worst on the primary coils. A cooler with a large frontal area will therefore be able to operate longer without defrosting being necessary. A well designed freezer should be able to operate for about 8 hours before a defrost is required, whereas a poor design may need defrosting every 2 hours.

Types of air blast freezers

Continuous air blast freezers

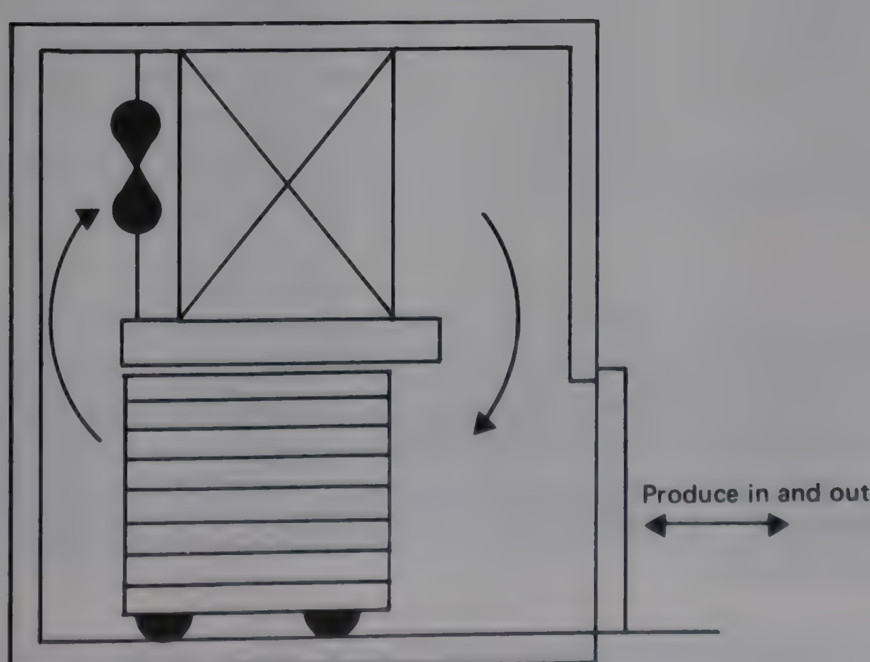
In one system fish are packed into trays and loaded on to trucks or trolleys which are moved through the freezer on rails (this is known as a batch-continuous operation). In the other system, fish are carried through the freezer on a conveyor belt. Continuous air blast freezers are most suitable for freezing similarly shaped products with similar freezing times.

Figure 20
Batch—continuous air blast freezer
with counterflow air circulation



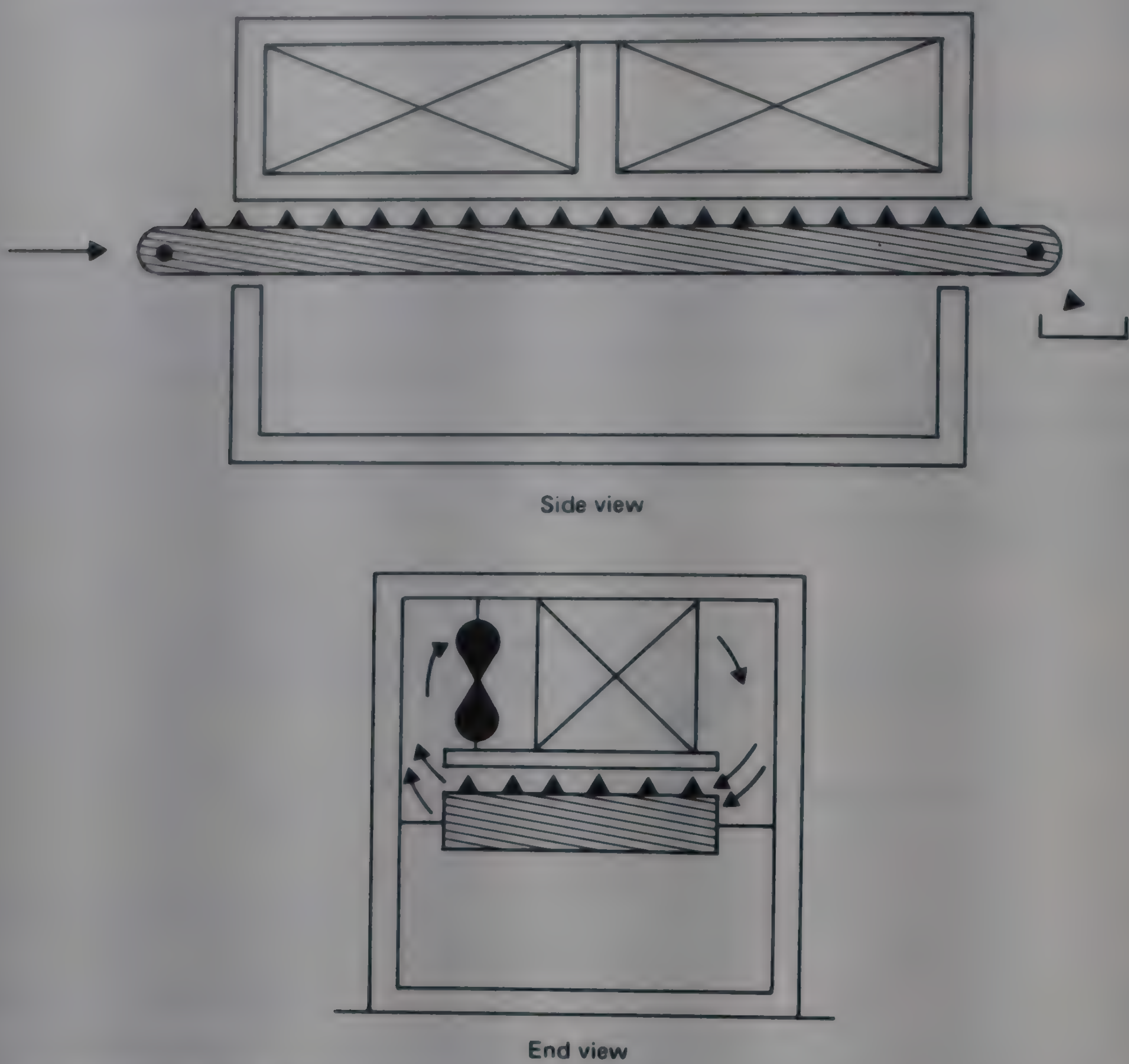
Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 21
Batch—continuous air blast freezer
with crossflow air circulation



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 22
Continuous belt air blast freezer with crossflow air circulation



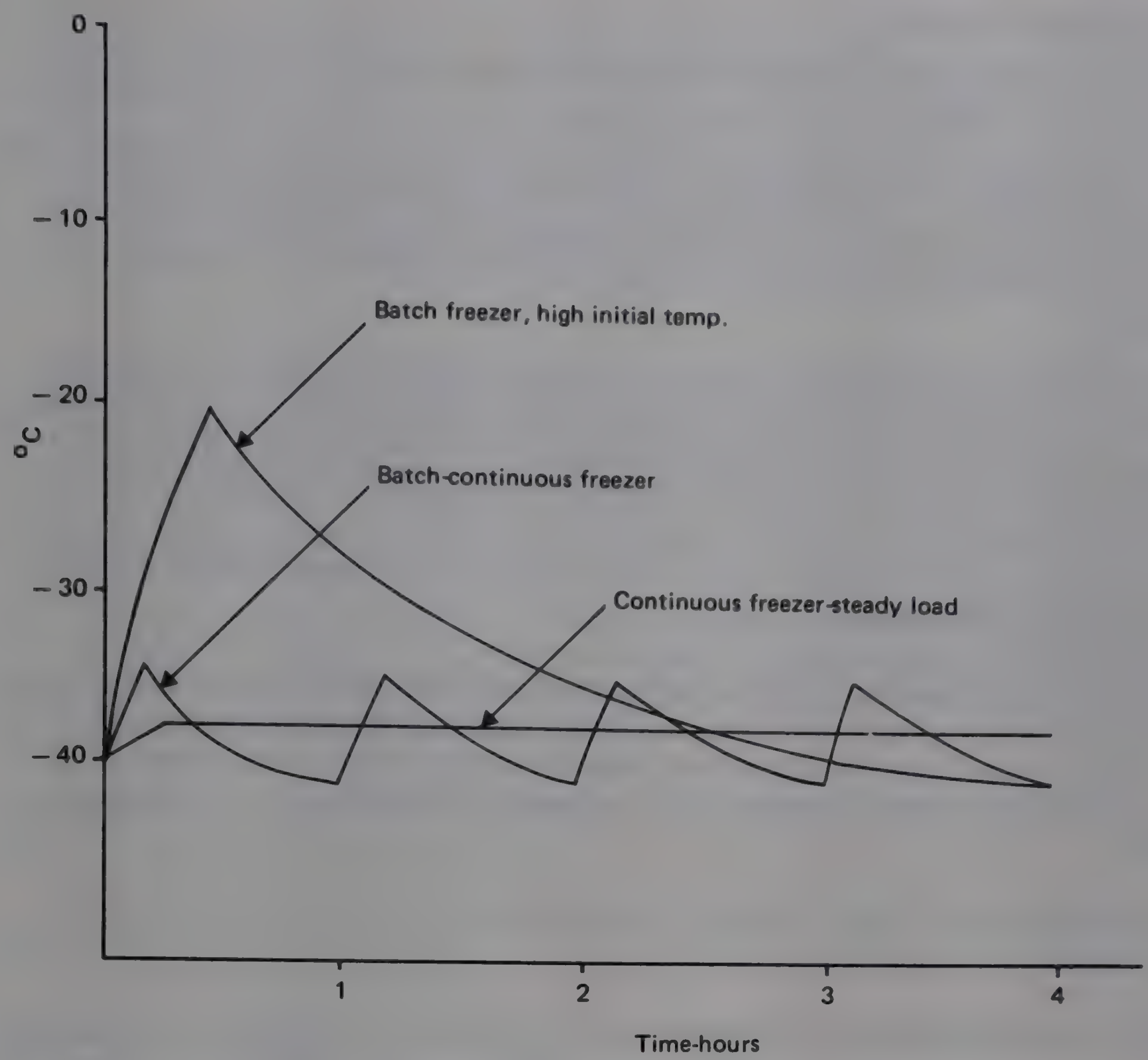
Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Batch-continuous: Figure 20 shows a typical arrangement for a batch-continuous air blast freezer with counterflow air circulation. The flow of air must be in the opposite direction to the movement of trucks, i.e., the coldest air over the coldest fish. Fully loaded trucks are pushed into the freezer and when the first truck is completely frozen another one can be pushed in to replace it. A problem which may occur during the freezing cycle is frosting of the rails, the trolley wheels becoming frozen if the wrong lubricants are used. One way of overcoming this is to use a crossflow cooling system as shown in Figure 21. Here the trolleys are loaded on and off across the tunnel and this avoids having to move a whole row within the freezer. Once the freezer is full no more trucks can be added until the freezing cycle of each truck load is complete. Individual timers for each bay are often included in designs.

Continuous belt or conveyor (Figure 22): This system should be used for small individual fish or portions of fish which are able to freeze within about 30 minutes. This restriction is necessary because any longer time would require the use of long and cumbersome belts with correspondingly higher costs. Double and treble belts can be used if the product is easily transferable, e.g., breaded fillets, and this helps to reduce the requirement for space. Spiral belts are also used for small individual quick frozen products (IQF).

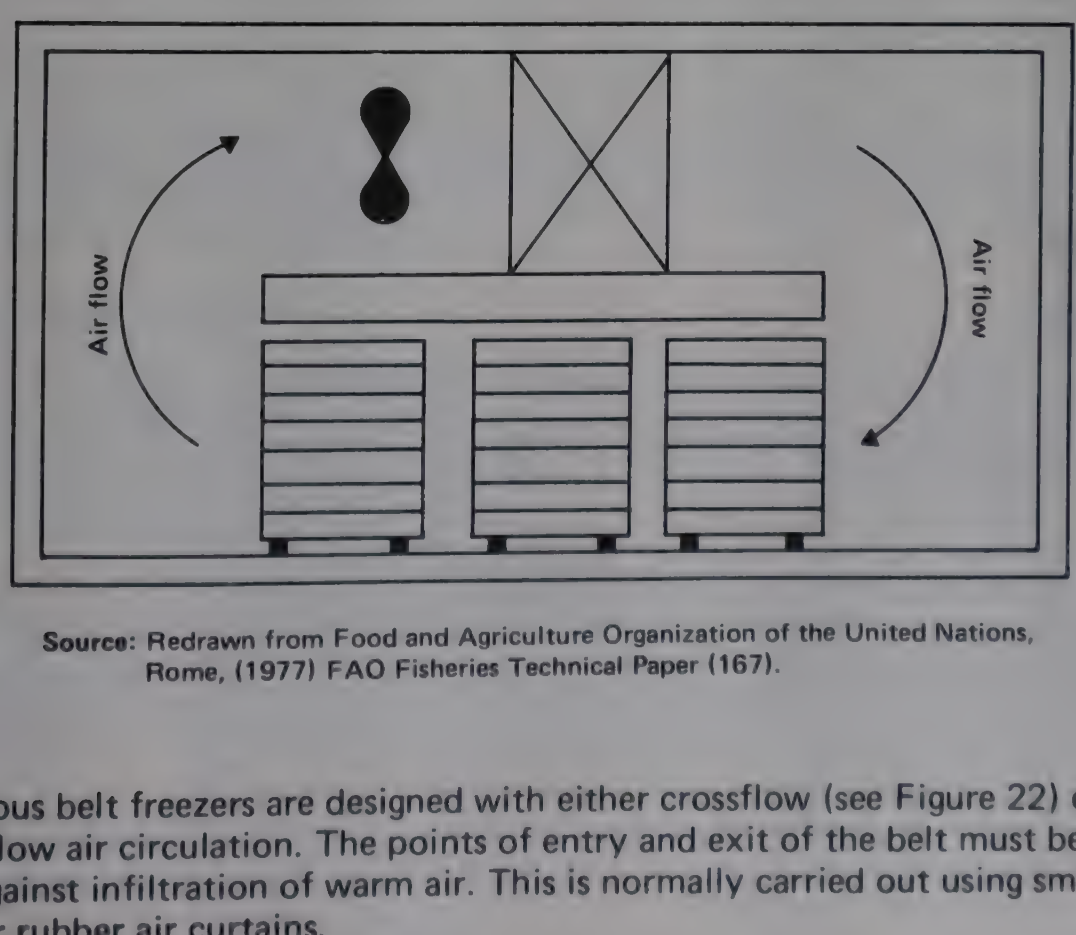
The belts used are mainly stainless steel interlocking mesh, although flexible or interlocking plastic mesh belts can be used. The former sometimes score the product which may also be difficult to remove from the belt. The latter reduces the rate of freezing by as much as 10 per cent.

Figure 23
Operating temperatures for different types of air blast freezer



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 24
Batch air blast freezer with side loading and unloading



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome, (1977) FAO Fisheries Technical Paper (167).

Continuous belt freezers are designed with either crossflow (see Figure 22) or counterflow air circulation. The points of entry and exit of the belt must be protected against infiltration of warm air. This is normally carried out using small plastic or rubber air curtains.

To keep freezing costs down, continuous freezers must be fully loaded. Belt speeds are normally adjustable to allow for different product freezing times; however, one product only can be frozen at one time using continuous belt freezers.

Batch air blast freezers

Batch air blast freezers use pallets, trolleys or shelf arrangements for loading the products. The freezer is fully loaded and, when freezing is completed, it is emptied and reloaded for a further batch freeze. Due to the mode of operation, batch freezers have a very high initial refrigeration load compared to batch-continuous and continuous type (see Figure 23). This large fluctuation in load requires a more sophisticated temperature control arrangement which can either be manual or automated.

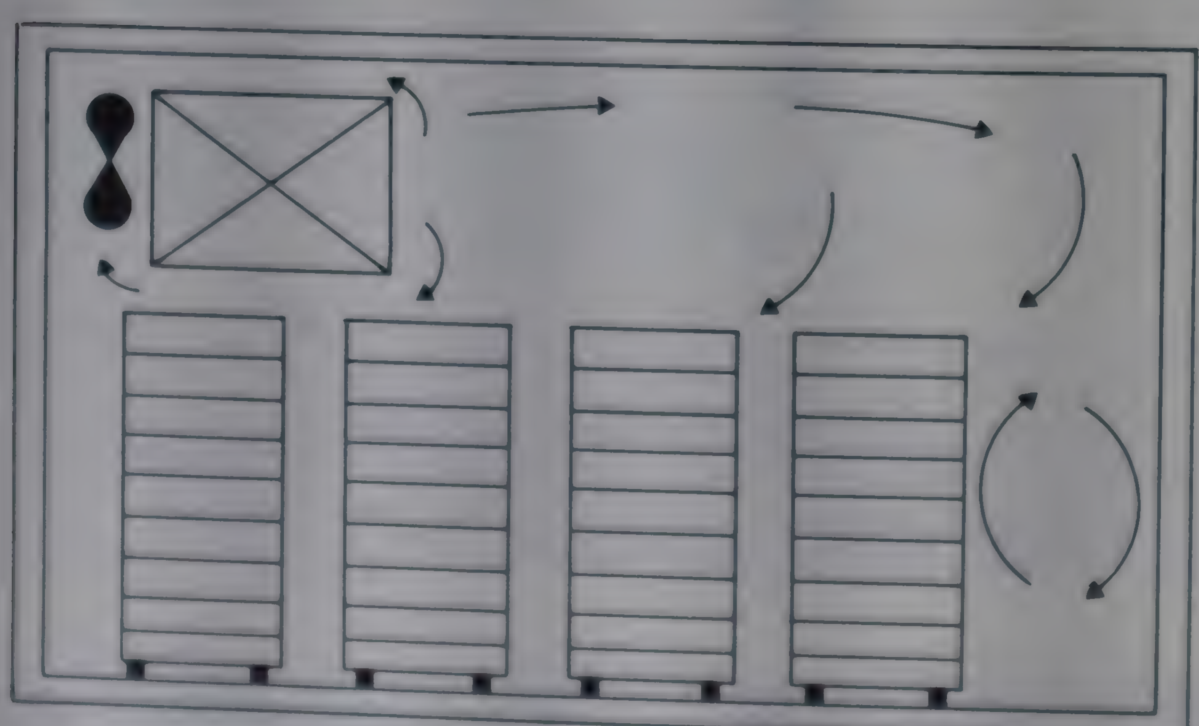
It is common practice however to operate a batch freezer on a batch-continuous basis for fish freezing and this helps to reduce the higher load. Care should be taken to ensure that warm fish are not placed upstream from frozen and partly frozen fish. Some batch freezers must not, however, be operated in this fashion, e.g., see Figure 24. In this case, trolleys are loaded from the side and warm moist fish could be loaded upstream from partly frozen fish. This type of freezer must therefore be filled prior to operation.

Loading of batch freezers: Due to their versatility batch freezers are often misused by operators who do not appreciate their limitations. Different products may have differing freezing times and space requirements and this affects the operation of the freezer. The freezer may, therefore, be overloaded or underloaded by a change in product.

The examples shown below illustrate what happens when products of different freezing times are loaded into a batch freezer.

Product	Plant capacity (t/h)	Load per batch (t)	Freezing time (h)	Loading frequency	Freezing rate (t/h)
A	1	2	2	Every 2 h	1
B	1	1	1	Every h	1

Figure 25
Room freezer with poor air flow over the surface of the product



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

In both examples above, the freezer is correctly loaded since the load matches the plant capacity for the weight of fish that can be frozen in 1 hour. However, 2 tonnes of type B would overload the freezer.

Different products can be frozen at the same time as long as close supervision is carried out to make sure that the plant is not overloaded and that correct freezing times are ensured.

There is a great variety of air blast freezer arrangements. Unfortunately, some designs are poor. For efficient freezing, the air must flow evenly over the fish. All too often the air swirls around in the open spaces of the freezer room as shown in Figure 25.

The methods of loading trolleys and of stacking boxes on pallets are also important. Air must be able to pass over the product. When wooden spacers are used, they must follow the direction of air flow and not block it. Furthermore, the trolleys or pallets must be sited correctly within the freezer.

Fluidised-bed freezing

In this process small IQF products, e.g., shrimp, are fed into a conveyor trough and are fluidised by a blast of cold air from beneath. One advantage of this method is that each small product is frozen separately and, if wet prior to freezing, will have a thin surface glaze which will help prevent freezer burn.

A modified version, termed a semi-fluidised freezer, has been used for freezing certain fish which are frozen individually.

CONTACT OR PLATE FREEZERS

Plate freezers and air blast freezers are commonly used by the fishing industry. Plate freezers are used for blocks of fish but do not have the versatility of blast freezers.

There are two main types:

1. *Horizontal plate freezers* (HPF) (See Figure 26.)
2. *Vertical plate freezers* (VPF) (See Figure 27.)

In both types the product comes into close contact with aluminium alloy plates, which contain circulating refrigerant, and is frozen into blocks. This is some times aided by the addition of water to help bind the fish together. All plate freezers have hydraulic systems which move the plates to compact the product and give higher density blocks. This also aids in quicker freezing and block release after freezing, as well as economising on storage space.

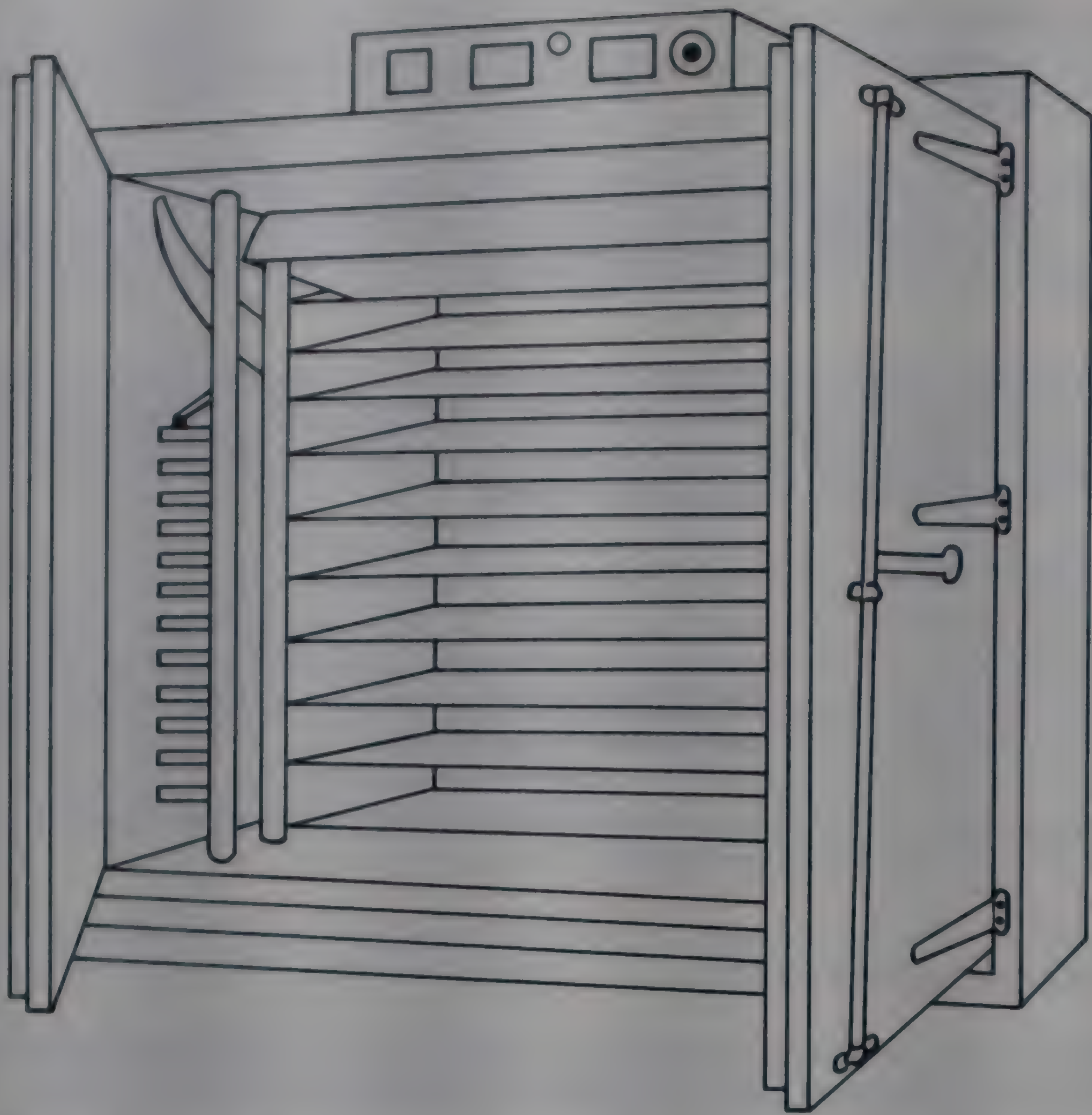
Horizontal plate freezers

In this type of freezer, the fish are packed into cartons which are fitted into aluminium freezing trays and are placed on the freezer shelves. A hydraulic system brings the plates into contact with the top and bottom of the product, thereby ensuring maximum heat exchange.

If care is taken not to spill water on the plates during loading of the freezer, a defrost is not essential after each freezing operation, perhaps only once or twice a day. Hot gas defrost is the quickest method of defrosting, and complete defrost may take 30 minutes or more. Defrosted plates must be free of ice and must be dried before re-use.

HPFs are most useful for freezing blocks of fillets (laminated blocks from 32 mm – 100 mm thick), for the preparation of fish portions, pre-packed retail cartons of fish and for packs of shrimps and prawns.

Figure 26
Horizontal plate freezer



Source: Adapted from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

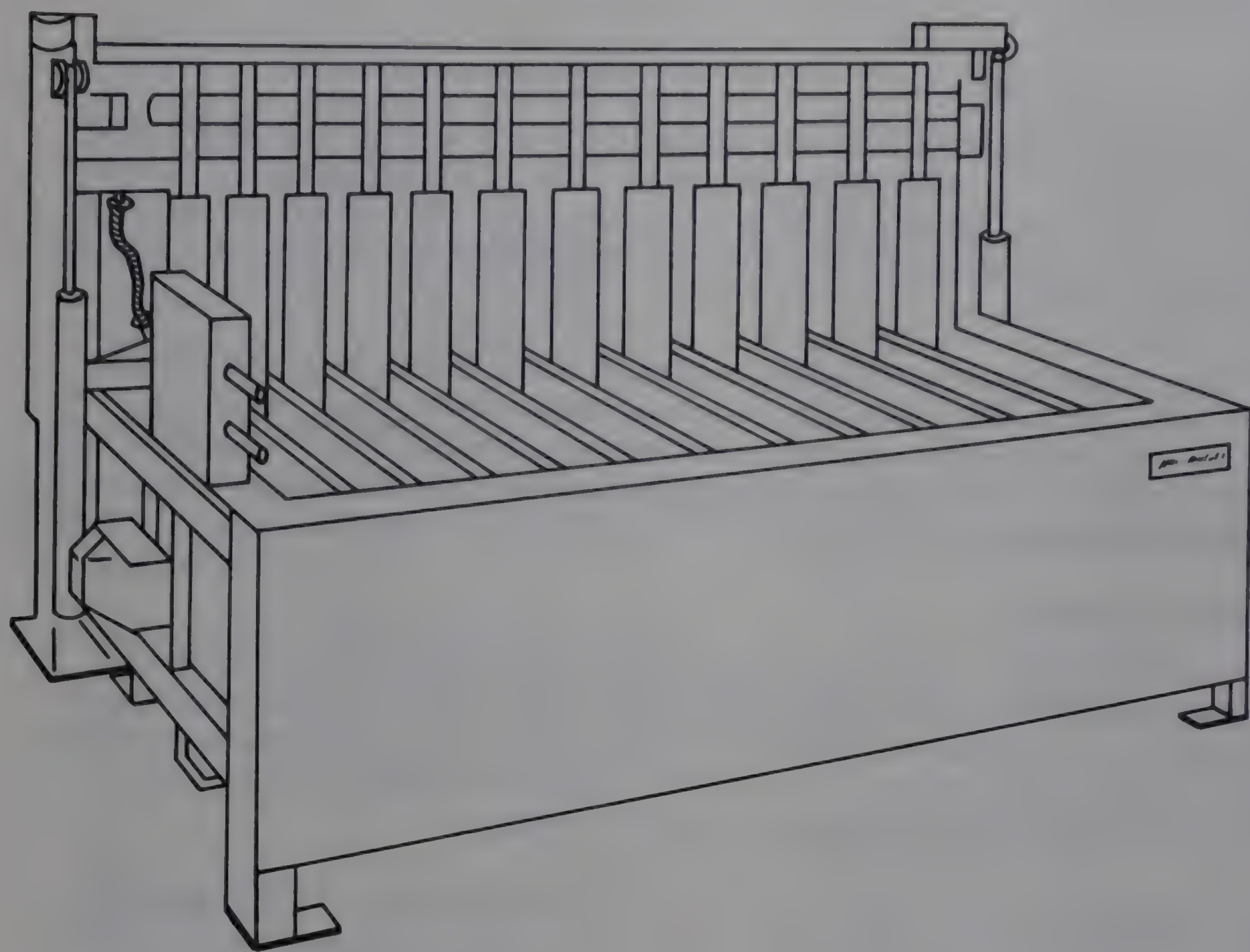
Vertical plate freezers

This type of freezer is particularly suitable for freezing whole fish at sea and for bulk freezing. The top is open and divided into up to 30 stations into which the fish are placed.

Marine fish, such as cod, form solid blocks when frozen, whereas fatty fish such as herring generally do not. In this case, water is added to bind them together to form strong blocks, which is particularly important at sea where rough handling can easily lead to block breakages. Wrappers are sometimes used, in which case longer freezing times are required. These are usually made of polythene lined paper bags which fit into spaces between the freezer plates. The maximum size of block is about 1 x 0.5 m. Thickness can be from 25 mm – 130 mm. A hot gas or liquid defrost is required to release the blocks from the plates quickly.

Different designs of VPFs have top, side or bottom unloading; generally the former are preferred simply for handling reasons. The size of the freezer should ideally be matched to the amount of fish available but, if there is a part load only, this should be frozen rather than risk spoilage by waiting for more fish. During the loading operation, the plates should be above 0°C in order to prevent the fish sticking. If this occurs it will preclude the formation of a dense block and render the process inefficient.

Figure 27
Multi-station vertical plate freezer with top unloading arrangement



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

SPRAY OR IMMERSION FREEZERS

In both of these methods of freezing, the product comes into direct contact with the refrigerant. These types of freezers find limited application in the fishing industry and may be suitable only for specialised products. They are generally more expensive to operate than plate and air blast freezers. Examples are:

- Liquid nitrogen freezers
- Carbon dioxide freezers
- Liquid freezant freezers
- Immersion freezers.

Liquid nitrogen (N_2) freezers

With this type of freezer the liquid nitrogen is sprayed directly on to the fish after they have been pre-conditioned by a countercurrent flow of cold nitrogen gas. The temperature of the gas is about $-50°C$ when it first comes into contact with the fish and, as the fish pass through the freezer, it falls progressively to $-196°C$ at which stage the fish are partially frozen. The fish pass through the freezer on a stainless steel belt and the temperature of the fish is liable to reach an equilibrium before being discharged from the end.

Liquid nitrogen freezing is very quick and requires little space other than that required for the liquid nitrogen. However, running costs are about four times those of a conventional air blast freezer and liquid nitrogen may be difficult to obtain in some areas of the world.

Carbon dioxide (CO_2) freezers

These freezers operate in a similar way to the liquid nitrogen type; in this case, liquid CO_2 is sprayed on to the product. The gas is often recovered and re-liquified which improves the efficiency. However, liquid CO_2 may also be difficult to obtain in remote areas.

Liquid freezant freezers

Liquid freezant freezers (LFF) use a purified florinated hydrocarbon called R12 which boils at −30°C at atmospheric pressure. Fish are loaded on to one conveyor and are sprayed with the refrigerant and then dropped into a tank containing R12. They are then transferred on to a horizontal belt where more refrigerant is sprayed to complete freezing.

Although the refrigerant is recovered in spray freezers, there can be considerable losses and, since recovery is by a conventional refrigeration system, LFF, liquid N_2 and CO_2 freezers have the usual requirements for operation and maintenance. The system is useful for IQF products but in some countries direct contact of food with R12 is not approved.

Immersion freezing

Immersion in sodium chloride (NaCl) brine was one of the earliest methods used for freezing fish. Many other liquids which have similar heat transfer properties cannot be used in contact with foodstuffs. Brine immersion freezing is still used for tuna which are to be canned. Not much salt is absorbed because of their thick skin and this fish is normally packed in brine in the can.

A eutectic solution of 22.4 per cent (85 per cent saturated) at −21°C is generally used. This is circulated at about 0.2 m/second. The brine tanks must be large (50:1; mass brine: mass fish) as must also the cooling coil. Other disadvantages of this system are:

- it gives rise to corrosion
- the product is difficult to handle
- further temperature reduction to −30°C is required

OTHER TYPES OF FREEZER

These are sometimes combinations of the types described above:

Sharp freezer: This consists of a room with cooling pipes arranged as shelves about 25 cm apart upon which the product freezes. These are generally inefficient in operation.

Drum freezer: This consists of a large rotating drum through which refrigerant flows. IQF products such as shrimp are fed on to this, stick to it and are scraped off by a blade.

Continuous brine freezer: Fish are frozen on a stainless steel belt cooled by refrigerated brine which is pumped onto or sprayed across the lower surface of the belt. A blast of air can be applied from above to enhance the process if required.

FREEZING TIME AND FREEZER OPERATING TEMPERATURE

Freezing time

Freezing time is the time taken to lower the temperature of the product from its initial temperature to a given temperature at its thermal centre. Since the recommended cold storage temperature for fish is −30°C, the freezer temperature must be lower than this. The outside of the product must cool rapidly to near the

freezer temperature, bringing the temperature at the thermal centre to about −20°C. Thus the average temperature of the fish will be close to the required storage temperature of −30°C.

Freezing time depends on:

- freezer type
- freezer operating temperature
- air speed in blast freezers
- product temperature
- product thickness
- product shape
- product contact area and density
- species of fish
- freezer operating conditions.

Freezer operating temperature

Freezer operating temperatures are fixed for those freezers which use a direct refrigerant/product contact. Air blast freezer temperatures, however, can be varied to suit the needs of the user.

Examples of freezer operating temperatures:

Batch air blast	−30 to − 37°C air
Continuous air blast	−35 to − 40°C air
Plate	−40°C
Liquid N_2	−196°C (N_2 gas at −50 to −196°C)
Liquid freon	−30°C (refrigerant) −40°C (condenser)
NaCl Brine	−21°C
Drum	−45°C

FREEZING DO'S AND DON'T'S

Freezing and cold storage *cannot improve fish quality.* However, if the following rules are adhered to for air blast freezing, the quality will be maximised for this situation:

- Avoid delays prior to freezing
- Keep fish well iced prior to freezing
- Maintain hygienic conditions at all times
- Do not overload freezer
- Do not underload freezer
- If possible, freeze in open trays
- Use trays which are robust and easily emptied and cleaned as well as good thermal insulators
- Dry and clean trays before use
- Load trays evenly on to the trolleys
- If freezing in boxes, ensure that these are full, with minimum air space
- If freezing in boxes on pallets, ensure that the boxes are stacked to allow air to pass between these, i.e., use spacers
- Freeze for the correct time

How to make good frozen products

While this paper primarily deals with the freezing process, it is important to remember that many other aspects of handling and processing of fish will ultimately affect the edibility of frozen fishery products.

1. Any reduction in the micro-organism population on the fish during freezing and cold storage will be more than nullified by growth during thawing – even if this stage is carefully controlled.
2. Any mishandling of the frozen produce during storage and distribution which causes the surface to thaw will allow microbial growth.
3. Poor thawing/cooking techniques will result in an increase in the microbial population.
4. Factors 2 and 3 will increase the risk of the end product being unacceptable because the resulting spoilage will cause 'off' odours and flavours or, at worst, the product may cause food poisoning.
5. The poorer the quality of the raw material, whether due to chemical or microbiological spoilage or both, the greater the risk of rejection by the ultimate consumer or importer; only the freshest (i.e. best quality) raw material should be frozen.
6. Whatever the cause of spoilage or development of food poisoning micro-organisms, the manufacturer will be blamed.

Having the above points in mind, the manufacturer of frozen produce cannot afford to accept anything but good quality raw material which is kept cool right up to the time of freezing; he must ensure that the work area is kept clean with no risk of the good quality raw material being contaminated from surfaces or residues of old fish; he must ensure that his work force are instructed in and maintain good standards of personal hygiene.

If the above points are not observed it is impossible to produce consistently good quality frozen produce. Even if the above points *are* observed, it is impossible to consistently provide the consumer with good quality frozen produce unless the process and cold chain are continually monitored to ensure good manufacturing and handling procedures as described below.

THE FREEZING PROCESS

Other lectures have discussed freezing theory and methods; it will be realised that, having obtained good quality raw material and kept it cool, especially during any preparation and packaging, it is important during freezing to remove the heat from the food as quickly as possible and, having dropped the temperature *at the centre* to about the cold store temperature, to transfer the food as quickly as possible to the cold store.

This depends on a well designed and managed freezing operation. Abuse of the freezing and refrigeration system, such as poor maintenance, may lead to reduced efficiency of heat removal, which, if not recognised, will mean that under-frozen, possibly unfrozen, produce will be transferred to the cold store. Such general problems are identified below, as are more specific problems associated with particular methods of freezing.

REMEMBER that the rate of freezing at any point in the food, and therefore the total freezing time, depends on:

1. The temperature of the refrigerant.
2. The thickness of the food (or more often the shortest distance to the centre from the surfaces in contact with the refrigerant).
3. The area of the surface of the food in contact with refrigerant.
4. The surface heat transfer coefficient (which controls the rate at which heat is transferred from the food to the refrigerant).
5. The thermal conductivity of the food (which influences the rate at which heat is transferred within the food to its cooled surface).
6. The density of the food.
7. The latent heat of fusion of the food.

THE REFRIGERATION SYSTEM

In a well designed freezing system the refrigeration plant will have been designed to give refrigerant at a specific, or small range of, temperature *for a specified heat load.* In common with most natural and mechanical systems, while it can withstand some slight variations outside the specification, frequent overloading or drastic under-loading will cause stress and wear and thereafter less efficient operation; this in turn may lead to higher refrigerant temperatures and so to slower freezing rates/longer freezing times. Some examples of bad practices are listed below.

Overloading:- the system will be designed for a particular maximum heat load associated with the early stages of the freezing process when there is a maximum temperature difference between food and refrigerant. The following will cause overloading: introducing food at a much higher temperature; leaving the door open or having poor seals on the doors (effectively refrigerating the work area); introducing a food having a much larger surface area for heat loss than normal.

Drastic underloading below the specified norm for the equipment results in valves and controllers 'hunting', thus causing excessive wear, and frequent starting and stopping of the compressors. In addition to abnormal wear under such frequent starting and stopping, it is likely that the required low refrigerant temperature would not be maintained in plate freezers.

Condenser temperature:- the compressor can only handle a limited pressure differential between the evaporator and condenser. Inefficient condensation will be caused by dirt or other obstructions on the fins in an air-cooled system and sediment or scaling on the fins in a water-cooled system; this will produce a reduced flow rate or unforseen high air/water temperature in either case and will result in high refrigerant temperature.

Poor maintenance:- in addition to mechanical faults, air or other non-condensable gases, or low levels of refrigerant, in the system will reduce the ability of the system to remove heat.

In order to produce good quality produce, the production manager must be sensitive to the problems associated with the refrigeration system. All the above factors will lead to slower freezing rates and perhaps incomplete freezing. A facility

for checking that the pressure and temperature in the evaporator and condenser, and refrigerant level in the reservoir, continually meet specifications and that the compressor is not running continuously or 'hunting' will help to ensure that the manager is able to manufacture good frozen produce.

THE PRODUCT

Variations in the product may influence the rate of freezing and freezing time; the effect of such factors are indicated below. The time required to freeze each type of product should be separately determined and adopted.

(a) The type of fish or fishery product — the thermal conductivity, density and latent heat are physical properties that vary between different types of fish, particularly between high and low fat content fish.

(b) The type of pack — the density of packing the fish if frozen in blocks, and the amount of water/glaze added, will affect the freezing time.

(c) The thickness of the pack — the thicker the pack, not only the longer the freezing time, but the slower the freezing rate at the centre; individually frozen items are best, especially if glazed, but require more labour.

(d) The type of packaging, if any is used — variations in the thickness of the card or the inclusion of a polythene liner can drastically affect freezing rates and times in a plate freezer.

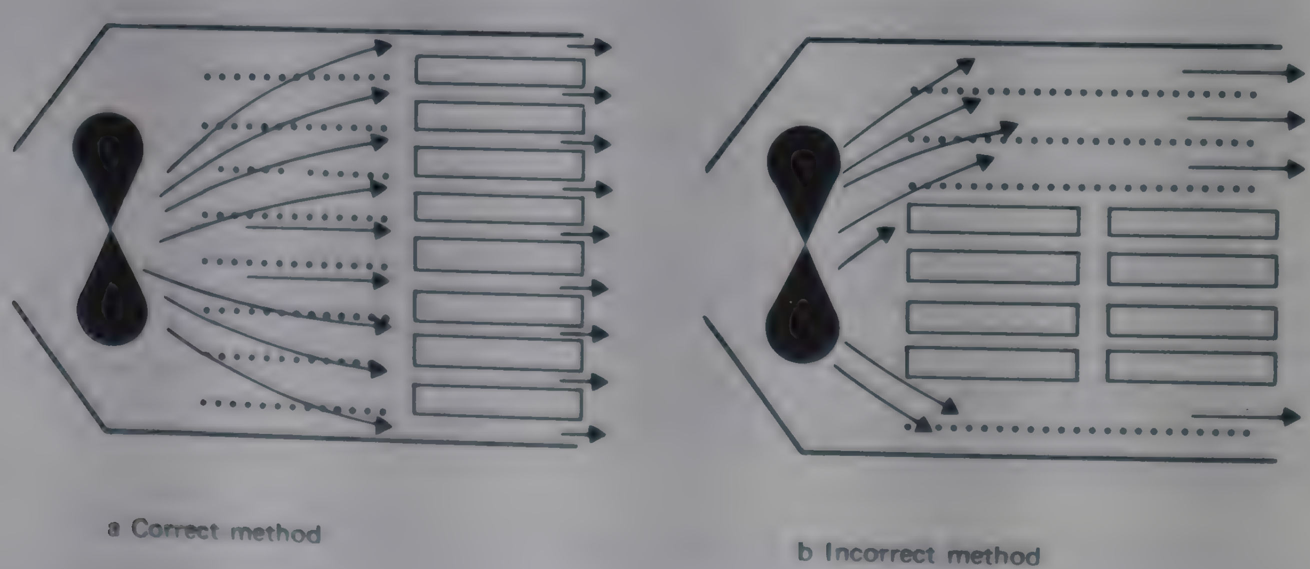
THE FREEZING METHOD

Blast freezers

It is important to remember that in blast freezers, the surface heat transfer coefficient, which influences the rate of freezing, is dependent on the air velocity past the product.

Surface heat transfer coefficient $\propto$ air velocity $^{0.8}$. This is particularly crucial for thinner products where a high air velocity close to the product surface will give fast rates of freezing throughout.

Figure 28
Part loading a blast freezer.



Air will always take the easy path. If part loading a blast freezer, it is best to load as shown in Figure 28a rather than as shown in Figure 28b where the air velocity past the produce will be reduced. In Figure 28a, freezing time will be about the same as for a full load while in Figure 28b it could be from twice to four times as long.

Similarly, the introduction of thinner blocks might give some reduction in freezing time but not in proportion to thickness if the same depth between the shelves is used since there will be more space for the air to flow at a slower speed.

While dealing with air velocity, it is important to remember that the fan requires regular lubrication.

It is equally important that the air should be able to lose its heat to the evaporator coils. If ice collects on the coils the heat is transferred at a slower rate and the air is less effectively cooled. Should the evaporator grid become fully iced up, there would be very little refrigeration effect. The evaporator coil should be regularly defrosted.

While the product must be left in the freezer long enough to ensure effective freezing, it is important not to leave unpackaged products in for too long; otherwise considerable dehydration, leading to freezer burn in the worst cases, will result. Glazing is frequently recommended where individual quick freezing techniques are used.

Plate freezers

Whether they are of a horizontal or vertical design, it is important to keep the plates clear of ice or frost; if allowed to accumulate, this will keep the product away from the plate surface, leaving air gaps which will act as insulation. It is, therefore, essential to clear the plates of ice/frost between each batch.

For the same reason it is important, particularly in the case of the horizontal unit, to ensure that each package sits properly on the plate; overlapping or irregularities will result in insulating air gaps between products and the plates.

Similarly, the compression effect of the plates is important to ensure good contact between the food and the plates. Excessive pressure, however, will damage the food. It is essential, therefore, that spacing bars are used at all times as specified by the equipment manufacturer (incorrect use may cause bowing of the plates which will also give poor contact); the bars should be purpose-built for each product of different thickness so that they are slightly thinner than the pack. Plates should be fully loaded to avoid bowing.

In the case of the vertical plate unit, unpackaged fish are often frozen into a block. It is important to ensure that the plates are fully defrosted before loading, otherwise there will be a tendency for the fish to stick to the plates before being placed in position. On the other hand, if defrosting is carried out for too long a period, the fish will tend to warm up before the freezing process begins.

Fish of similar size should be carefully packed in between the plates, mixing sizes will lead to the small fish being damaged. Fish too large for the system have to be frozen in a blast freezer, while any distorted by *rigor mortis* have to be left on one side until *rigor* is completed.

As in the case of the horizontal unit, slight compression of the plate is important to give good contact. At the end of the freezing process it is *essential* to go through the defrost cycle in order to release the blocks from the plates — failure to do this will cause the blocks to break up as the plate pressure is released. The blocks should be handled carefully to prevent them breaking and may require glazing before storing.

Immersion freezing

This technique is primarily effective because there is good contact between the cold liquid and the fish and the fluid has a higher heat capacity compared to air. These advantages are lost, however, if the immersion liquid is not of the correct concentration (and therefore temperature) or if the flow of liquid is impeded by any factor, for example, overloading of the tank by putting in more fish than the system is designed to handle.

Liquid nitrogen freezing

Fish will suffer considerable physical damage from thermal shock if brought directly into contact with liquid nitrogen or a spray of liquid nitrogen. Pre-cooling the product to below its freezing point, perhaps using the cold nitrogen gas, is essential.

COLD STORAGE AND DISTRIBUTION

The frozen product should be immediately transferred to the cold store, preferably at −30 C but definitely not above −20 C. There should be *no* delay which might allow the product to start to warm up.

The management and design of cold stores and transport for frozen fish is covered elsewhere but the following is a resumé of the important details.

The manufacturer should remember that temperatures above −20°C, and fluctuating temperatures, will cause his product to deteriorate very rapidly. It is in his own interest to ensure that, at every stage in the cold chain between himself and the consumer, the cold stores are maintained below −20°C (n.b. the term 'cold store' is frequently mistakenly used to describe 'chill stores' operating at +5 to +10°C – which is cold in the tropics); that refrigerated transport is down to −20°C before his frozen product is loaded; and that the frozen product is directly transferred from cold store to refrigerated transport and vice versa, allowing *no time* for it to warm up.

IT MUST BE REMEMBERED that, in countries where frozen foods are very popular and regularly consumed by the bulk of the population, the cold chain is the weakest link in providing the customer with good quality frozen foods. IT WILL BE MUCH MORE DIFFICULT in the tropics, where fewer people are familiar with frozen foods, to ensure good handling procedures during storage and distribution.

Despite the general tone of this paper highlighting all the problems concerned with the production of good frozen foods, in many ways the biggest problems associated with giving the customer good quality frozen fishery produce occur after the product is frozen.

Summary

The rules to follow then are:

1. Use only good quality raw material.
2. Keep the raw material cool.
3. Maintain good standards of hygiene in the factory.
4. Regularly service the refrigeration equipment.
5. Identify the freezing time for each product.
6. Follow freezing procedures precisely.
7. Do not shorten the process time.
8. Transfer the frozen product directly to the cold store.
9. Try to ensure good handling and management throughout the cold chain.

Cold store design

The means of maximising cold store efficiency through its proper use will be discussed in more depth in a later session on the use of cold stores. In this session, we will comment on the functional design and choice of materials used for cold store construction.

THEORETICAL CONSIDERATIONS

The spoilage of fish due to protein denaturation, autolytic spoilage, bacterial spoilage, fat oxidation and dehydration can be slowed down through the freezing process and subsequent cold storage. However, in order to maintain an efficient method of cold storage a number of important considerations must be followed in terms of design and materials.

The major concern of the cold store operator is undoubtedly dehydration which, once evident, can lead to fat oxidation and protein denaturation. The control of heat flux is vitally important in cold storage. For example, air at a temperature of $-20°C$ can hold up to 3 times as much water vapour as air at $-30°C$ and thus a small fluctuation in temperature can result in product dehydration. Any source of heat ingress must therefore be controlled. The measured rate of dehydration between fish stored in a well-designed and operated store and one that is badly designed and operated has been shown to vary by a factor of up to 100. The worst stores are often ones in which unfrozen or partially frozen fish are placed. This imposes too high a heat load on the plant and dehydration of other stored materials occurs rapidly.

The most important design factors, therefore, are:

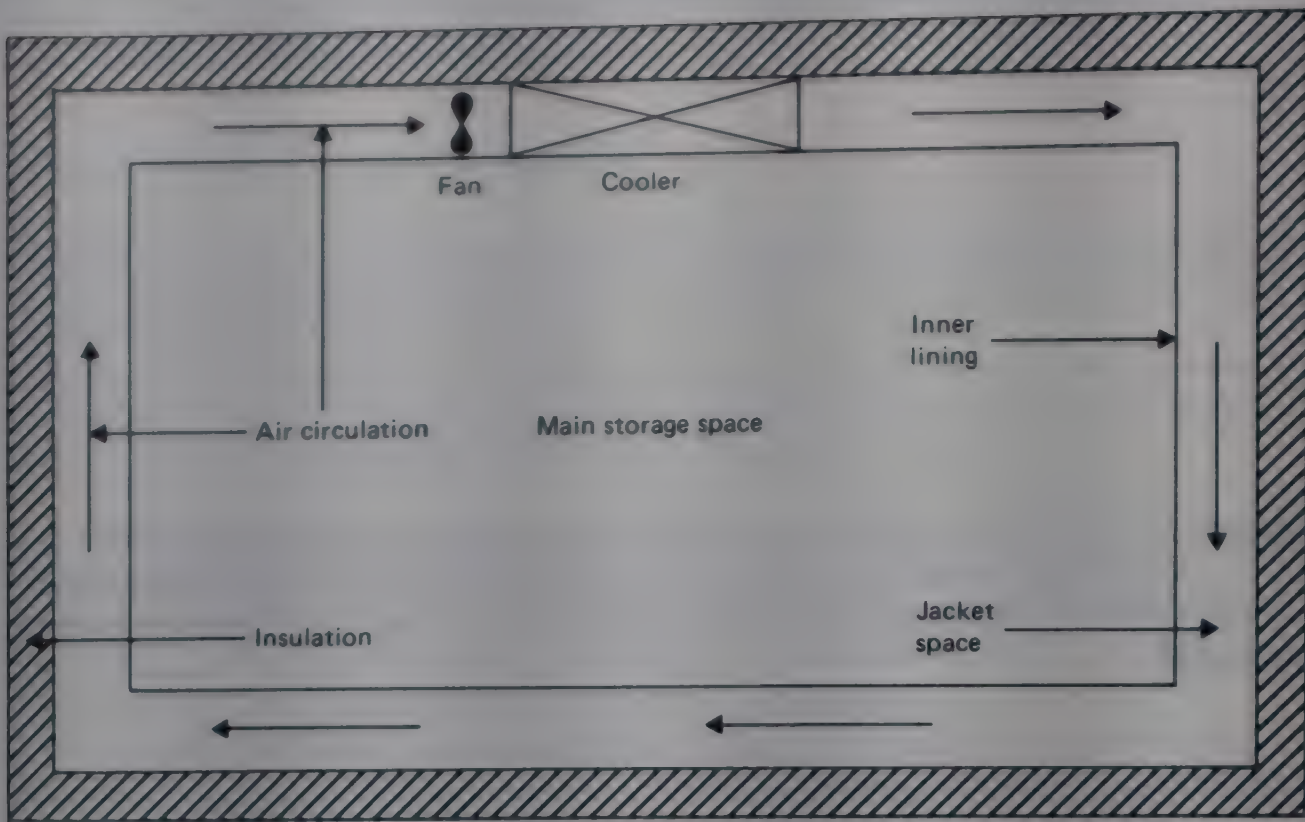
- low temperature
- uniform temperature
- steady temperature
- good air distribution
- minimum rate of air calculation
- minimum heat ingress

TYPES OF COLD STORE

Jacketed cold stores (Figure 29)

This system represents the ideal method of construction but is expensive. The main storage space is maintained at a very constant temperature and high relative humidity by the passage of refrigerated air through the walls, ceiling and floor. Since the storage space is sealed off completely, internal fans are not required and the air within the store is very still. Very high product quality results from storage in this type of store. However, very few have been built due to the high cost of construction.

Figure 29
Jacketed cold store.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Gridded cold stores

In this type of store, cooler pipe grids cover the walls and roof and these maintain the required conditions very efficiently. As with jacketed stores, fans are not required and frost build-up on the grids is slow, requiring defrosting perhaps only once every few months.

Again the cost of these stores is high due to the following reasons:

- there are large amounts of complex pipe grids
- a large quantity of refrigerant is required
- the weight of plant requires stronger construction methods
- maintenance requires a large reservoir for the refrigerant.

Finned grid stores

These are similar to gridded stores in that large surface areas of cooling surface are exposed within the storage area. However, in this case, fins are used on the pipes to increase the heat exchange rate and, because of the increase in efficiency, finned grids are usually mounted only on the ceiling.

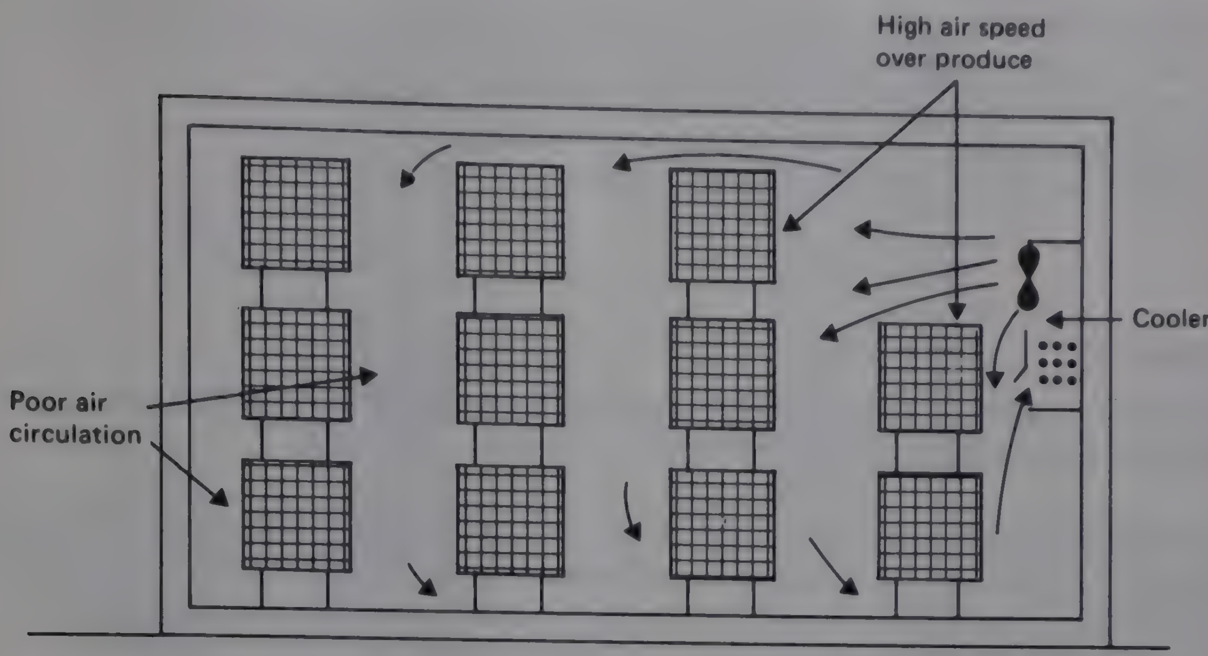
Unfortunately, by using fins, frosting above the cooler will tend to block the cooling surface and defrosting must be carried out more regularly. This can cause water to drop off on to the product and so is carried out only when the store is empty. Of course, this may be inconvenient and it is often the case that this type of store is operated beyond the stage where defrost is required. Moreover, because the cooling pipes are only on the ceiling, the storage conditions will not be quite as good as with the gridded stores.

Stores with unit coolers

This is the most commonly used type of cold store in which unit coolers are used with fan circulation of the air. They have the following advantages:

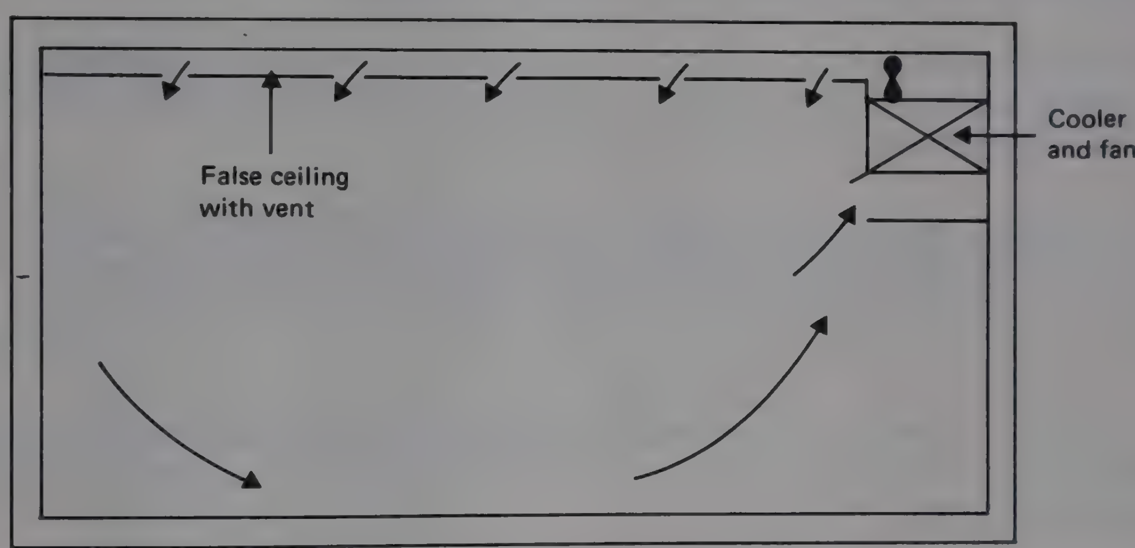
- they are cheap
- they contain a small charge of refrigerant
- they are easily defrosted
- they do not require a heavy supporting structure.

Figure 30
Uneven air distribution in a store with unit cooler and fan circulation.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 31
Cold store with ducting, or false ceiling and vents, to give uniform air distribution.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

The main disadvantage is usually the poor air circulation achieved, which results in poor storage conditions (see Figure 30). Ducting systems are now widely used to distribute the cold air uniformly throughout the store (see Figure 31). Multiple units are advisable for the following reasons:

- they can be defrosted in series without affecting the total plant
- in the event of breakdown, the other coolers should be able to maintain conditions.

Defrosting is carried out either by hot gas (on the larger plants) or by electrical heaters.

IMPORTANT DESIGN FACTORS

The design of the cold store radically affects the product storage life through its ability or inability to maintain a low, uniform and steady temperature with the

minimum of air circulation. We have just considered the advantages and disadvantages of some different cold store designs and the following factors are vitally important as regards their optimal operating efficiency:

- *Insulation:* the walls must be adequately insulated and vapour sealed to prevent the passage of heat and frost heave.
- *Prevention of air ingress:* good air lock design is essential.
- *The proposed method of storage and handling.*
- *The amount of refrigeration required.*

Insulation

The use of good thermal insulation is a prerequisite in cold store design and the type of insulation and its deployment are vital to efficient operation.

The theoretical considerations relevant to the choice of insulators will be discussed in our session on the use of chill and cold stores. In cold store design, the problems involve choice of the *best insulator for the job.* Listed below are some common insulators along with their advantages and disadvantages:

Cork: expanded cork was one of the original insulators used. It has good thermal conductivity characteristics but can allow the passage of water vapour. It is strong and does not burn well but is expensive due to the scarcity of the trees from which it is obtained.

Glass fibre: glass fibre matting has better insulatory properties than cork and is fireproof. However, it settles and has no structural strength.

Expanded and extruded polystyrene: these materials are widely used insulators and are produced in panel form for structural strength. The compressability is poor and they are destroyed at fairly low temperatures (75°C).

Polyurethane foam: the low initial thermal conductivity of this foam gradually increases with time. Its main advantage is that it can be foamed into a cavity or on to a surface. The vapour resistance is good but it will burn, giving off toxic substances.

Granular materials: sawdust, crumb polystyrene, granular cork, vermiculite etc. are often cheap and readily available. They tend to settle, however, and allow water vapour to pass through.

The importance of insulation

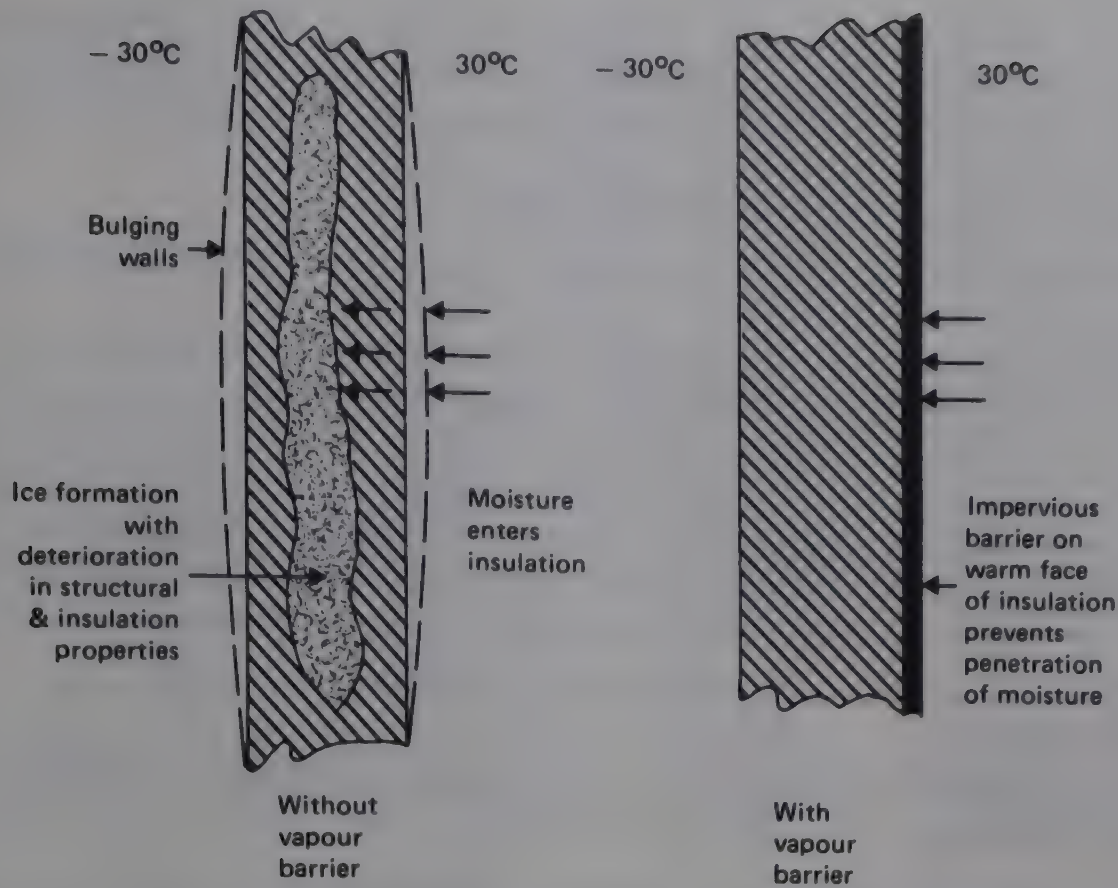
The choice of insulator not only depends on its low thermal conductivity but also on the following:

- water and water vapour resistance
- ability to withstand rot and vermin
- strength for the walls and floors
- toxicity
- flammability
- price

The first of these requirements is probably the most underrated and, if it is not adhered to, can lead to the problems outlined below.

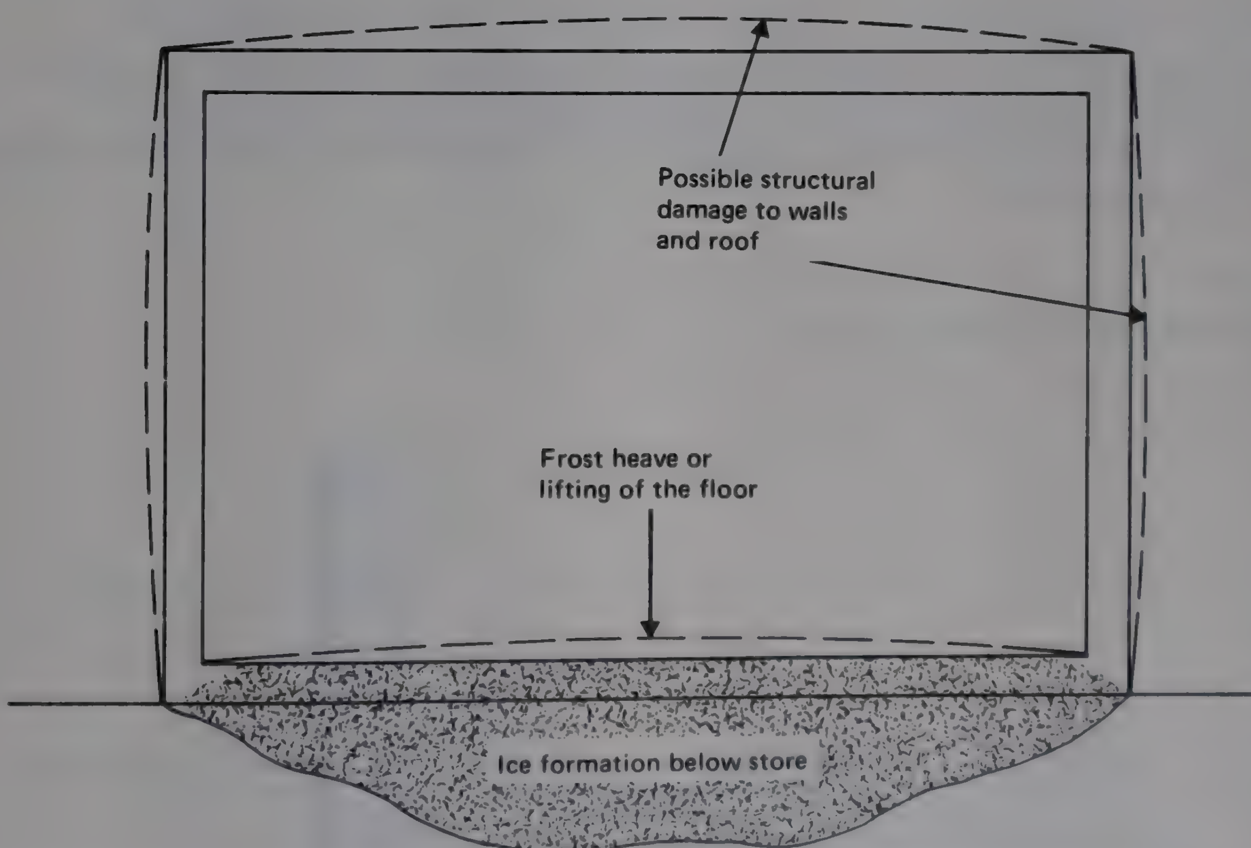
Vapour barriers: Air at ambient temperature is able to hold more moisture than cold air, i.e. the partial pressure of the water vapour outside a cold store is generally higher than that inside. This is especially so in a warm moist tropical country. This difference in partial pressure creates a gradient down which the water vapour will pass from outside to inside through the insulation of the cold store walls. As the water vapour cools, it condenses and, at 0°C, solidifies into ice. This will continue

Figure 32
The function of a cold store vapour barrier.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 33
Frost heave.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

until the ice has built up so much that it affects the insulation properties of the wall and also weakens the structure (Figure 32).

To prevent this from happening, a *vapour barrier* outside the insulatory wall is essential. This must be a gas seal to prevent the ingress of any water vapour any-

where on the exterior surface of the building. Vapour barriers can be provided by coating the walls with bitumen or cladding them with sheet metal sealed at the edges.

Frost heave: This occurs as a result of inadequate floor insulation and is caused by a build up of ice under the floor. As the quantity of ice builds up, it can cause the floor to lift and crack, and may also affect the foundations and walls (Figure 33).

There are two methods of preventing frost heave:

- Sub-floor heating under the insulation, usually by hot glycol circulated through pipes (Figure 34).
- Sub-floor ventilation (Figure 35). The building is elevated on to support piles. This can be advantageous for loading of lorries etc.

Air ingress

Air from the outside brings with it both warmth and moisture. This moisture quickly builds up on the cooler and a small rise in temperature will enhance water loss from the stored products. There are a number of ways of preventing air ingress:

(a) Air locks (Figure 36) – these are unpopular since they are regarded as a hindrance.

(b) Air curtain with door – this type is often abused and the door is often left open for too long.

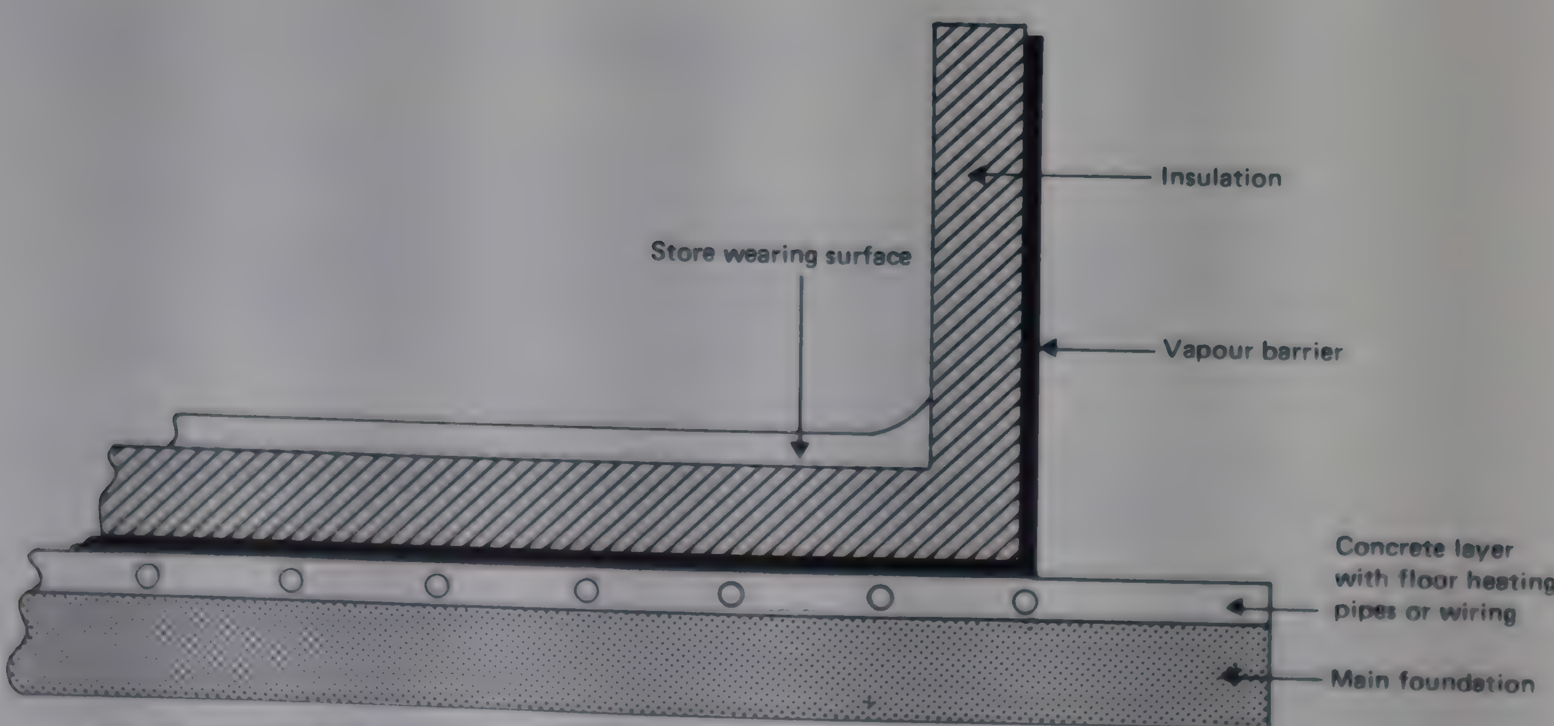
(c) Plastic curtains – these can be suspended from an inner and outer opening and form a very workable air lock.

(d) Hatches – these are small openings usually combined with mobile conveyors and mounted on the wall to prevent loss of cold air.

Product handling and storage

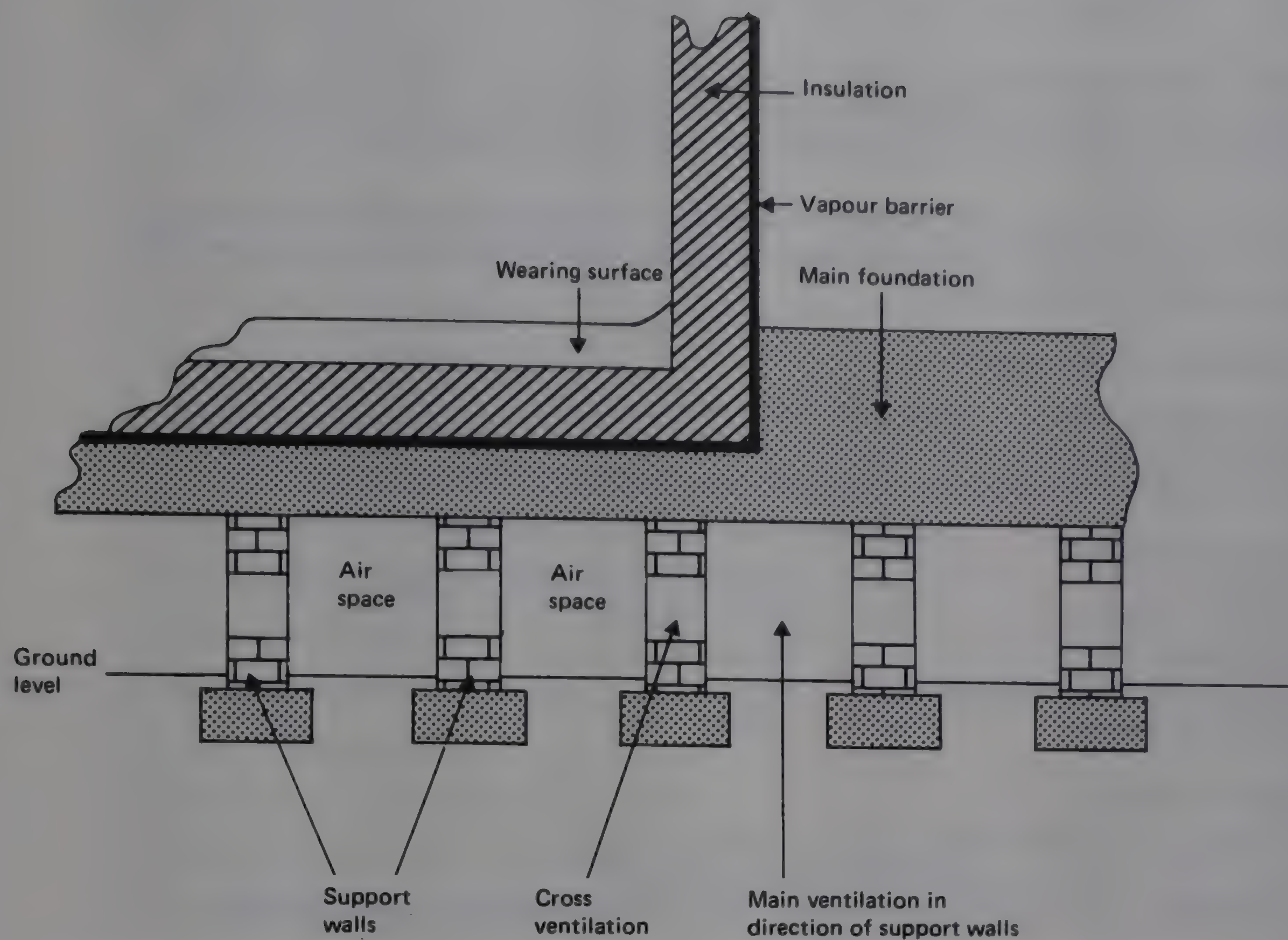
During the design stages, consideration must be given to the proposed methods of handling and storage of the product. For example, if the cold store has been designed with sub-floor ventilation to prevent frost heave, loading bays can be constructed outside the store which will accommodate different lorry designs by lifting up or down hydraulically. These bays must have sufficient manoeuvring space for sorting out pallets.

Figure 34
Frost heave prevention using floor heating.



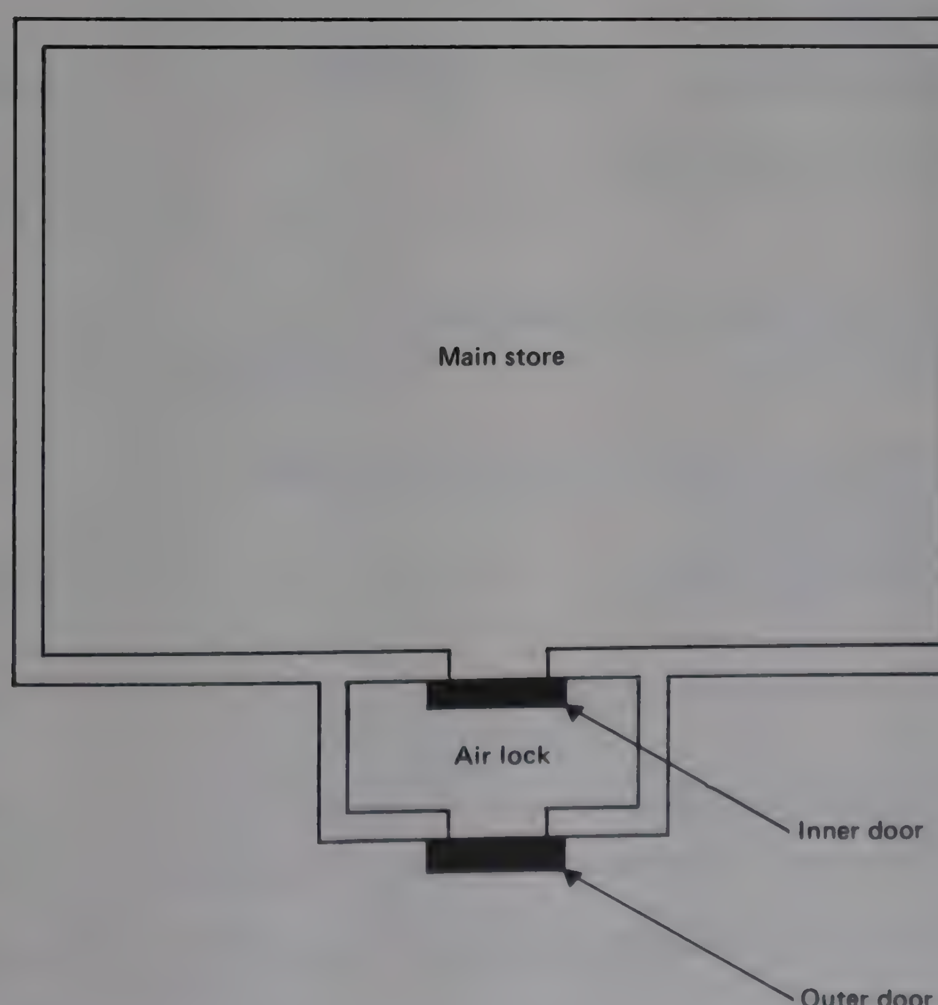
Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167)

Figure 35
Frost heave prevention using subfloor ventilation.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

Figure 36
Air lock.



Source: Redrawn from Food and Agriculture Organization of the United Nations, Rome (1977) FAO Fisheries Technical Paper (167).

In tropical countries, it would be advisable to have a refrigerated loading and sorting area. This acts as a buffer zone to the warm moist air and should be enclosed and refrigerated to about 10°C. The approximate area should be 25 per cent of the store area.

Other considerations are the means of product handling within the store, e.g., conveyors, trolleys, fork lift trucks, and the stowage method, e.g., boxed pallets, cage pallets, bulk storage. This will be dealt with in greater detail in a later session.

The layout of the store will be determined by the type of product stored as well as the stowage methods. Passageways should be clearly defined and loading bays should be charted by the operator.

Refrigeration requirements

The calculation of exact requirements for refrigeration is very complex and this is dependent on a great number of, often, indefinable variables. The following calculations, however, will give some idea of the complexity:

Store specification

Capacity	1 000 m^3
Insulation thickness	0.25 m of cork
Surface area	771.5 m^2
Maximum ambient temperature	35°C
Store temperature	–30°C

Load calculation

1. *Insulation heat leak* through walls, ceiling and floor:

$$\text{Heat leak} = \frac{\text{surface area} \times \text{temperature drop}}{\text{thickness of insulation}} \times k \text{ (thermal conductivity)}$$

$$\text{Therefore, heat leak} = \frac{771.5 \times 65}{0.25} \times 0.037 \qquad = 7\,476 \text{ kcal/h}$$

2. *Air changes*

   Average of 2.7 air changes in 24 hours

   Heat gain (35°C and 60% RH air) = 40 kcal/m^3

   Store volume = 1 000 m^3

$$\text{Therefore, air change heat gain} = \frac{1\,000 \times 2.7 \times 40}{24} \qquad = 4\,500 \text{ kcal/h}$$

3. *Lights* (left on during working day)

   1 000 watts = 860 kcal/h

4. *Men working*

   1 man working at –30°C gives off 378 kcal/hour

   Therefore, 2 men working at –30°C give off = 2 x 378 kcal/h = 756 kcal/h

5. *Product load*

   5.5 kcal/kg for fish load at average temperature of –20°C

   Fish loaded = 35 000 kg/day

$$\text{Product load} = \frac{35\,000 \times 5.5}{24} \qquad = 8\,020 \text{ kcal/h}$$

6. *Fan load*

   3 x 1/3 hp = 923 kcal/h

7. *Defrost heat*

   1 defrost of 8 400 watts for 1 hour (recovered over 6 hours) = 1 209 kcal/h

Total calculated refrigeration load (i.e. sum of items 1–7 above) = 23 744 kcal/h

Total refrigeration requirements with allowances = $23\,744 \times \frac{24}{18}$ = 31 658 kcal/h

(Taken from Food and Agriculture Organization of the United Nations, Rome (1977). *FAO Fisheries Technical Paper* (167), pp 53–54).

The minimum requirement for refrigeration is during the period when there is only an insulation heat load and the fans are in operation. This may account for only 30 per cent of the maximum load and it is important to consider this when refrigeration units are purchased. Units can be obtained with two or more compressors which can be switched in as the load increases.

ORDERING A COLD STORE

A great deal of information should be supplied to the designer and contractor by the buyer. The most important factors are the following:

1. Storage capacity required.
2. Operating temperature.
3. Ambient temperatures.
4. Stowage methods proposed.
5. Maximum average temperature of product when loaded.
6. Throughput of product and utilisation of store.
7. Insulation preferred.
8. Method of cooling preferred.
9. Plan of proposed site.
10. Electrical supply (voltage and phase).
11. Spare parts requirements and backup facilities required.
12. Description of local expertise in the installation of equipment.

The use of chill and cold stores

Chilled and cold storage are two distinctly different storage methods, although both involve a reduction of the ambient temperature down to within fairly strictly defined limits in order to preserve foodstuffs. Both methods are practised to a great extent by the developed nations and this allows longer periods to be spent at sea between landings, as well as extending the depot life of the product during storage and distribution. However, to be effective, certain practices should be observed and followed and these are discussed below.

CHILLED STORAGE

The rate of spoilage due to both microbiological and autolytic deterioration is greatly reduced through a temperature reduction. The process of chilling is basically as far as one can go without actually freezing the fish tissue, and the use of chilled storage facilities should be regarded as an extension to common icing practice, i.e., chill stores are designed to *maintain* and not *attain* chill temperatures. Fish should previously have been iced in the normal way, this preferably having occurred during the fishing trip or, alternatively, immediately after the catch has been landed.

The use of ice is vital to the chilling process due to its excellent properties as a cooling agent. This has been discussed in detail in an earlier session.

The importance of ice in chill stores

Ice has a very large cooling capacity for a given weight, is harmless, cheap and cools the fish quickly through immediate contact. The process of continuous melting depends on having a good supply of ice maintained at the desired temperature of 0° C whilst at the same time keeping the fish moist and preventing dehydration.

There are other methods of chilling fish: for example, blowing cold air over the fish; packing dry ice (solid CO_2) around the fish; immersing the fish in chilled water. Of these the last, using mechanically cooled seawater or seawater with added ice, is a suitable alternative means of chilling large quantities of small fish, especially on board fishing boats. However, the use of cold air alone to chill fish, and its misuse as the prime cooling agent in cool stores is unsatisfactory for the following reasons:

(a) unlike ice, cold air has a poor cooling capacity;

(b) air will remove moisture from the surface of the fish and thus dry out surface tissues;

(c) it is difficult to maintain a constant temperature: the air originating from the cooling coils may well be below 0° C and thus there is the risk of freezing the fish within their proximity.

Once the temperature has been reduced by icing, chilled conditions should be maintained, using both ice packed around the fish and circulated chilled air at

about 1–2°C to prevent the ice from melting too quickly. It should be stressed that the use of refrigeration is to *augment the insulation of the store,* i.e., to slow down the passage of heat into the fish and *not to actually chill them.*

Stowage methods

Chilled fish are most commonly stored in boxes which are of wood, plastic or aluminium. These are stacked in blocks with air spaces between so that air can still circulate freely. It is important that boxes are not stacked against the walls of the store or directly on to the floor, as these may be sources of heat and air will not circulate freely.

Adequate drainage is a prerequisite of a properly designed store and it is also important that the height of stacks of fish in boxes is not greater than can easily be managed by hand.

FROZEN STORAGE

As with chill stores, cold stores are designed to *maintain* and not *attain* the reduced temperatures of frozen fish and must not be used for the latter.

The theory of freezing has been dealt with in a previous session. Immediately after the fish have been frozen, however, they should be glazed or wrapped.

Glazing

This is a process by which fish, once frozen, are coated with a film of ice by spraying with water or by brushing or dippping in water. Glazing has two major functions:

(a) Prevention of *freezer burn:* this phenomenon results in fish of a wrinkled dry appearance with a tough texture and is due to water loss from the surface of the fish. In a cold store, water in the air is condensed on the freezer coils as 'frost', thus maintaining a reduced water vapour pressure within the store atmosphere. Any fish which is exposed to the cold store air will therefore lose water, i.e., the tissue ice sublimes leaving partly dried flesh behind.

(b) It helps to prevent oxidation: this process still occurs at sub-zero temperatures and the oily fish such as herring and mackerel which have a high concentration of labile polyunsaturated fats are particularly prone to oxidation and concomitant development of rancidity.

The ice layer formed during glazing acts as a suitable barrier, therefore, in helping to prevent both freezer burn and oxidation.

Cold storage life

All products entering the store must be at or near the frozen storage temperature which, is recommended to be –30°C. Fish that have been quick frozen to –30°C will keep for many months if stored correctly. The exact storage period depends on:

(a) the species

(b) the fat content

(c) the treatment prior to freezing

(d) the physiological state.

Very fresh cod (a temperate water, non-fatty fish), stored for less than 24 hours on ice prior to freezing, will keep for 8 months in prime condition and up to 4 years before it becomes inedible if glazed and packaged efficiently and stored at –30°C. Herring (a fatty, temperate water fish) will keep for 6 months in prime condition and up to a year in good condition under the same regime.

Stowage methods

These will be discussed fully in the next session. In outline, stowage can take the following forms:

(a) packaging frozen fish into cartons or boxes and stacking on wooden pallets;

(b) packing frozen fish into wire cage pallets;

(c) bulk storage.

REQUIREMENTS FOR EFFICIENT CHILL AND COLD STORES

Maximum efficiency when storing any material at low temperatures chiefly requires the minimising of heat flow down the temperature gradient from outside to inside the store. In order to carry this out, the best insulating material available must be used for construction.

Insulation

A good insulating material is one which, when placed between two bodies of different temperatures, will slow the rate of heat exchange. A measure for heat conductivity (or efficiency of insulation) is called the k value. This is a measure of the amount of heat in kilocalories passing every hour through 1 m^2 of material 1 m thick when there is a temperature difference between the two surfaces of the material of 1°C. The more efficient the material, the lower the k value.

The following materials are commonly used in the construction of stores:

Materials	*k value*
Wood	0.14–0.16
Brick	0.70–0.80
Cork	0.40
Glass fibre	0.03
Polyurethane	0.02–0.03
Expanded polystyrene	0.02–0.03
Air	0.02

As can be seen, air is a very good insulator but, being a gas, thermal convection plays a greater part in heat transfer than conduction. However, any materials which entrap air within small interstices (for example, corrugated board, expanded polystyrene etc.) provide excellent thermal barriers.

To demonstrate the effectiveness of one insulant *vis a vis* another, we can carry out a simple calculation as follows:

Calculation 1

To calculate the amount of heat entering through the lid of a simple wooden box, held at 30°C and containing ice, (area 0.4 x 0.6 m, the wood being 0.01 m thick). The heat flow through the lid depends on four factors.

1. The area of the lid = 0.4m x 0.6m = 0.24m^2
2. The thickness of the lid = 0.01 m
3. The temperature difference between the outside and the inside of the box = 30°C
4. The k value of the material of the lid = 0.15

$$\text{Heat flow} = \frac{\text{k x area x temperature difference}}{\text{thickness}}$$

$$= \frac{0.15 \times 0.24 \times 30}{0.01} = 108 \text{ kcal/hour.}$$

Calculation 2

All dimensions and temperatures as for calculation 1 but using 0.01 m of polyurethane foam instead of 0.01 m of wood.

k value for polyurethane foam taken as 0.02

$$\text{Heat flow} = \frac{0.02 \times 0.24 \times 30}{0.01}$$

$$= 14.4 \text{ kcal/hour}$$

In practice, thicker insulation is used which further reduces heat loss. Scaled-up calculations similar to the above can be applied to full-scale chill and cold store design.

As well as being a good thermal insulation material, the materials used for construction should also have certain other characteristics. It must be:

(a) water resistant, i.e. be non-absorbant and with a good vapour seal;

(b) rot and vermin-proof;

(c) light but strong with good compression strength, especially for floors;

(d) cheap;

(e) non-toxic;

(f) non-flammable.

Store design

The efficient use of a cold or chill store not only depends on the choice of materials used for construction but also on the actual functional design and operation of the building.

The following points should be borne in mind:

1. As previously noted, drainage for chill stores is most important. With wet floors, there is a serious risk of slipping and a suitable high-friction surface should be used.
2. When deciding on size of the store, allowance should be made for the passage of people, trolleys etc.
3. In order to maintain a steady temperature, air locks should be used with air curtains if possible.
4. Location of the store should be such as to minimise heat gain, i.e., inside a building. This is most important in tropical countries.
5. The floor must be strong as well as insulated: the passage of fork lift trucks can easily disrupt a weak flooring material. Freezing of the ground beneath the store when inadequate floor insulation is used could result in frost heave where the subsoil freezes, expands and disrupts the foundations.
6. The amount of refrigeration required depends on a number of factors which must be taken into account at the design stage:

   (a) ambient temperature and insulation type;

   (b) quantity and temperature of products entering the store;

   (c) number of doors and door openings in a normal working day;

   (d) size of store.

   When obtaining quotations for proposed chill/cold stores it is important to provide the contractor with the following additional information:

   (e) type of water supply, e.g. pressure; salinity;

   (f) land availability;

   (g) stowage method to be adopted;

(h) electrical supplies available;
(i) refrigerant required, e.g. ammonia, or R12, R22 or R502;
(j) spare parts required.

Once the store is operational, maximum efficiency can be achieved by following these rules:

1. Products entering the store should be either pre-frozen to the cold store temperature or pre-chilled.
2. Products in boxes or pallets should be clearly marked and dated, and strict product rotation practice should be observed.
3. Free flow of air around the products is essential to maximise the refrigeration efficiency.
4. Monitoring of store temperatures should be routine and full records should be kept.
5. Frozen products must be protected by glazing of packaging.
6. If two doors are in operation, only one should be used at a time.
7. There must always be ice surrounding the fish in a chill store.

Storage and distribution of chilled and frozen products

In the last two sessions, we looked at the requirements and considerations for the most effective design and use of chill and cold stores. Now we will discuss the distribution and storage methods used for chilled and frozen products.

STORAGE OF CHILLED FISH

The need for continued chilling of fish after purchase still applies, whether it is destined for filleting or other processing and, as we have seen, the use of ice is vitally important for this. By mixing fish with crushed or flake ice, the temperature can be reduced to, and maintained at, 0°C much more quickly than by placing the fish without ice in boxes in a chill store. Air is such a poor conductor of heat that to cool the centre of a 64 kg container of fish would take several days in a chill room running at 0°C, but only a few hours using ice. The melting ice also effectively keeps the fish moist and prevents it from drying out.

However, it is not enough just to put ice in the box; it must also be packed in such a way as to exert its maximum cooling effect on the fish. Very often ice is packed only at the ends or top of the box and this has very little effect since the fish at the centre of the box will not come into contact with the cool melt water; e.g. a 7.5 cm-thick layer of fish iced only at the top takes more than 24 hours to cool down from 10 to 1.5°C. The same thickness of fish iced at top and bottom, however, takes only 2 hours to cool the same amount.

The thickness of the layer of the fish has more significance in terms of the rate of temperature reduction than has the initial temperature of the fish. Doubling the thickness of the layer of fish roughly quadruples the time to reach the required temperature at the centre of the layer.

How much ice is required?

Table 1 shows the theoretical amount of ice required to cool 6.5 kg of fish to 0°C from various initial temperatures, assuming no heat is taken up from outside.

Table 1

Weight of ice needed to cool 6.5 kg of fish to 0°C

Initial temperature of fish °C kg	Weight of ice
18	1.5
15	1.2
13	1.1
10	0.8
7	0.6
5	0.4
1.5	0.1

Of course, extra ice will be required to combat the extra warmth from outside. The cooler the fish, the less ice is required for initial cooling. Assuming that the fish and ice are completely insulated from the ambient temperature, then, using the above figures, no ice will be left when the fish reaches 0°C. Since it is impossible to have perfect insulation, there are various factors which are important in considering the amount of ice to be used. These are: the ambient temperature; length of journey; insulation and/or refrigeration of the transport; position of load. In many cases, *outside heat consumes more ice than the heat from the fish;* hence the importance of insulation in, for example, tropical countries.

Table 2 shows the approximate amount of ice melted in two sizes of fish box by outside heat.

Table 2

Melting of ice in a wooden box by heat from air

Outside air temperature °C	Weight of melted ice in 12 h	
	13 kg box	38 kg box
27	4.5	9.1
21	3.6	7.3
15	2.7	5.2
10	1.8	3.4
5	0.9	1.6

From Tables 1 and 2 we can calculate the approximate amount of ice required for our fish as follows:

Example

Temperature of fish = 10°C

Ambient temperature = 27°C

Storage time = 24 hours

Amount of fish = 13 kg

Therefore, *ice required to cool fish* (Table 1) = 2 x 0.8 = 1.6 kg and *ice melted by air* (Table 2) = 2 x 4.5 = 9.0 kg.

Therefore, *total ice required = 10.6 kg*

This is roughly a ratio of 1:1 ice to fish. If the store were to be *insulated,* this ratio could be as low as 1:5. Where insulation is inadequate it can be augmented with refrigeration, the function of which is to *remove heat entering the container walls, not to chill the fish.*

Stowage methods

It is common practice to pack whole and gutted fish in boxes of up to 45 cm deep although, to prevent physical damage occurring to the bottom layers of fish, delicate fatty fish such as herring or sardine should not be held in boxes of more than 20 cm deep.

Fish that are not gutted at sea are normally gutted as a first procedure on coming ashore because of the risk of autolytic and bacterial spoilage. Prepared fillets are held in shallow boxes usually 15 cm deep. In all cases, the ice should be in the form of a layer in the bottom of the box prior to filling and a layer on top of the fish (as already discussed). Since fillets can be damaged physically and through leaching, the common practice is to place a layer of paper or polyethylene around the fish so that it does not come into direct contact with the ice.

The boxes should be stacked in blocks with air spaces between so that air can circulate freely. It is important that the boxes are not stacked against the walls

of the store or directly on to the floor as these may be sources of heat, and air must be able to circulate around the fish between the stacks and walls of the store. In many small chill stores stowage of the boxes is by hand, so it is important that the height of stacks of fish in boxes is not greater than can easily be managed by the operatives.

The temperature within the chill store must be just above 0°C so that any ice present on the fish when they are placed in the store will continue to melt slowly and keep the fish cool and moist. In this way, the ice within the boxes will last longer than it would at high temperatures and thus reduce the risk of the fish drying out. If temperatures below 0°C are used there is a risk that the fish will partially freeze with consequent gross structural damage to the fish and possible acceleration of autolytic spoilage.

DISTRIBUTION AND RETAILING OF CHILLED FISH

The fish trade in the UK as it is known today has developed largely because for many years it has relied on railways for distribution. More recently, road transport has become more important and nowadays less than half the fish leaves the port by rail.

Rail distribution

Boxes of iced, chilled fish, whether from chill store or market, are loaded on to fish vans which measure roughly 1 300 cubic feet. These are insulated with a 5 cm-thick glass fibre layer, sandwiched between the light alloy body panels. Although the vans should be cooled prior to loading, this is not in fact normal practice and the loads, therefore, have to come to equilibrium which may take some time. Sometimes ice is sprayed over the load before the vans are sealed to speed up the reduction in temperature.

Solid CO_2: Solid carbon dioxide or dry ice is sometimes used and blocks of this are hung within the van to lower the air temperature. However, the cooling effect of this material is only about twice that of ice despite its much lower temperature (−140°F), and, with the cost being approximately 10 times that of ice, it becomes uneconomical to use. There is also the risk of actually freezing any fish which are stored near the dry ice.

Blast chilling: This is another new approach which involves spraying liquid carbon dioxide over the load. This converts to solid and gas phases and settles over the load, displacing the warm air. However, as with solid CO_2, there is the same risk of freezing the fish.

Road transport

Road transport of chilled fish is to some extent less standardised than rail transport. In some cases, boxes of iced fish are transported merely under tarpaulins and very quickly rise in temperature. In other cases, insulated and refrigerated lorries are used and the fish can be sent long distances and maintained at a temperature of 0°C.

It is sometimes the case that a truck is used for *both* chilled and frozen transport on different occasions. This may lead to problems, as carrying wet fish may saturate the insulation, thereby impairing its efficiency. The thicker insulation that frozen transport requires also leads to carriage of needless excess weight when carrying chilled fish.

Ice in the retail shop

In the shop, as at all other stages of distribution, fish should be kept cool, clean and moist using ice. Boxes delivered to shops should be opened, re-iced and placed in chill stores if necessary. Retail displays should be:-

(a) well drained

(b) insulated from beneath

(c) covered with a display shield (clear plastic or glass)

(d) screened against sunlight, lighting and heaters.

Fish should be displayed:

- on top of, and surrounded by, a layer of ice and
- in single layers.

STORAGE OF FROZEN FISH

Fish that have been frozen by any of the standard techniques of freezing should be protected by glazing prior to loading into the cold stores, unless they have already been placed in a consumer pack.

Glazing

Evaporation of water from the surface layer of fish in cold stores causes damage to the product by dehydration and also promotes oxidation of fat. Glazing by dipping the frozen product into water, or by brushing or spraying with water, forms a protective layer around the fish which may represent from 2 to 7 per cent of the weight of the block. The water glaze evaporates during storage and, as long as this layer is maintained, water loss from the flesh should not occur.

Glazing is not necessary for fish which are packed into retail containers; these provide protection from water loss and oxidation through their impermeability.

Storage life

Even if fish are properly frozen within a few hours of catching, glazed and subsequently stored properly at $-30^\circ C$, they will not keep indefinitely. Bacteria will remain dormant but slow autolytic changes and oxidation still take place. The higher the temperature, the faster these reactions occur. For example, in tests carried out at Torry Research Station, gutted white fish stored at $-10^\circ C$ stayed in prime condition for only 1 month and became inedible after 4 months. However, at $-30^\circ C$, they remained in prime condition for 8 months, becoming inedible after 4 years.

Fatty fish, such as herring and salmon, do not keep as well as white fish, such as cod, which have low fat contents.

Factors limiting cold storage life

1. *Protein changes:* proteins are denatured very slowly even at the low temperatures involved in cold storage. This limits the shelf life because of the development of undesirable texture. Water drip occurs after thawing and the flesh becomes spongy.

2. *Fat oxidation:* oxidation of the polyunsaturated fats in fatty fish occurs during storage giving rise to rancid off-flavours and discoloured flesh. This can be prevented to some extent by glazing and/or the use of antioxidants within the glaze.

3. *Dehydration:* frozen fish may dry slowly in the cold store even under good operating conditions. This is undesirable for the following reasons:

(a) loss of weight

(b) enhancement of protein denaturation

(c) enhancement of fat oxidation.

Dehydration of frozen fish results in *freezer burn* where the skin becomes dry and wrinkled and the flesh spongy and light.

Careful store, design and operation will help to minimise water loss and this was discussed in earlier sessions. One important factor, however, is the need to ensure that all products entering the store are at or near the cold store temperature. If they are warmer, water loss will occur very quickly.

Stowage methods

Pallets – mechanised storage: Frozen fish can either be packed in boxes or cardboard cartons and stacked on to wooden pallets or, if the fish are large or irregular in shape, they can be loaded into wire cage pallets. Both types should be stackable up to 4 pallets high and easily dismantled and handled by fork lift trucks.

Pallet stacks, however, should be kept separate and away from walls and roof, as well as raised above floor, to ensure efficient air circulation around the product. Distances recommended are as follows:

from floor – 100 mm
from walls – 200 mm
from ceiling – 500 mm

Hand stowage: This can be advantageous where the cold stores are small and labour cheap. Products are stacked by hand on shelves within the store.

Bulk stowage: This is used for the storage of whole fish such as tuna. It is not, however, recommended. Products can become stuck together through pressure melting of the ice and this makes handling very difficult. Bulk-stowed fish are often mishandled during initial storage and removal from the store – this can cause physical damage and bruising.

DISTRIBUTION AND RETAILING OF FROZEN FISH

The majority of frozen fish in the UK is transported by road in insulated refrigerated trucks. The remainder is carried by rail using insulated wagons.

The use of insulated trucks alone, without the use of supplemental refrigeration, may be suitable for short trips but is dependent on the following factors:

– size of load
– insulation
– ambient temperature
– air ingress.

Fish transferred from one cold store to another must be transported in insulated vehicles, preferably with a built-in cooler to maintain an air temperature of about –20°C.

The method of refrigerating a vehicle's storage space may be one of the following:

(a) Mechanical refrigeration using forced *air convection* or a wall cooler. A jacketed vessel may also be used.

(b) Rechargeable *eutectic plates.*

(c) *Solid or liquid* CO_2 or *liquid* N_2 can be used.

The refrigerated vehicles are suitable for transporting up to 15 tonnes of product.

Loading the containers

It is normal to pre-cool the containers prior to loading; rapid handling during loading prevents excessive temperature rise. The use of whole pallets rather than individual boxes helps to maintain low temperatures because of the reduced surface area in relation to volume.

Boxes etc. must not be stacked against the vehicle walls, floor or ceiling as these are sources of heat and the circulation of cold air within the container would be prevented. This is of particular importance when using unrefrigerated transport. In tests carried out on frozen produce, temperature rise in the middle of the load was negligible after 15 hours, whereas the temperature had risen by about 13°C in the outer layer, some 300 mm from the sides of the vehicle with which it was in contact. The products within this area occupied about 60 per cent of the total volume in a 5 x 2 x 2 m container, a fact not often appreciated.

Retailing

It should be noted that, once frozen fish have been thawed out, they should be treated like wet fish and iced.

Extended frozen storage in the shop is not advisable as dehydration occurs quickly in a normal freezer cabinet, especially of the open-topped type often used today, unless the product is protected in a good quality retail pack.

Design and construction of fish working premises

SITE

The plant should be erected as close as possible to the source of supply of raw material to avoid delays in handling. A site where catcher vessels can berth is best, provided that other requirements can be met. These take the following factors into account:

1. Some operations, particularly fishmeal manufacture, produce offensive odours and are best sited away from, and down wind of, the nearest town.
2. Many operations produce quantities of liquid effluent containing protein residues; the need to dispose of these without causing pollution problems should be borne in mind.
3. Areas where other industries produce smoke, dust or odours which may taint fish should be avoided.
4. The cost of erecting buildings depends on the nature of the ground; areas where expensive piling may be needed should generally be avoided. Such land may be cheap, however, and the total cost of land purchase and building on alternative sites should be considered.
5. If the product is to be taken away by land, all-weather roads are needed. Shipping by rail can be considered. If perishable high value products such as live lobster are to be shipped, proximity to an airport is an obvious advantage.
6. Many operations need large quantities of potable (drinking) water. This may be taken from the local authority supply or from a private borehole or dam. Clean sanitary seawater can be used for some operations, e.g., for washing down.
7. Premises should not be sited near refuse dumps, these always harbour vermin such as flies and rats.
8. Some operations have a high power demand. It is usually cheapest to use the local authority power supply if this is reliable and can be brought on to the site at a reasonable cost; bringing power on to a site can be expensive. A diesel generator is noisy and makes for unpleasant working conditions.
9. Good communication is important. If there is no telephone can a radio-telephone be used?
10. The nearer to the market the plant can be sited the better.
11. Many operations require large quantities of ice; if the plant can be sited near to a reliable source of cheap ice this is an advantage. If not, ice-making machinery will be needed. The possibility of generating a surplus for sale to offset costs can be considered.
12. Supplies of, e.g., packaging materials will be needed; if the suppliers are far away, costs will be high.

BUILDINGS

Buildings must be big enough to avoid crowding of people and equipment. Any fish working factory should be designed and built specifically for its intended purpose. Figure 37 shows a possible layout for a shrimp freezing plant as an example.

All buildings should be at least 3 m high internally. They must be well constructed and kept in good repair. All areas where the product will be handled must be kept separate from any part such as living quarters or offices or engineering facilities. Fish should not be processed in the same room as meat, frogs, chickens etc.

Construction must prevent entry of insects, birds and vermin such as rats and mice.

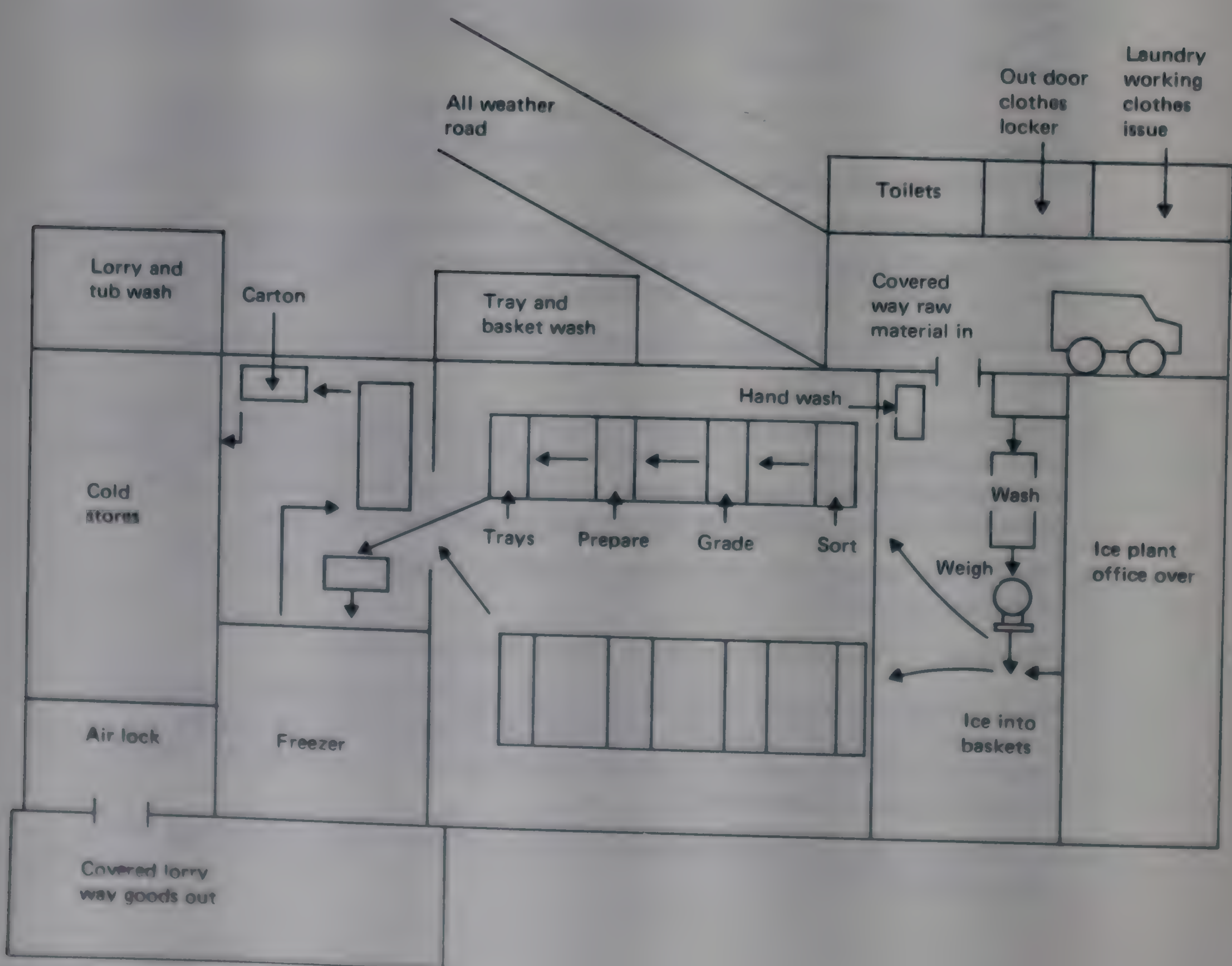
Single-storey buildings are preferable to multi-storey buildings; this avoids having a load-bearing second floor, and makes the movement of raw material and products easier. It is also difficult to arrange adequate drainage above ground floor level.

Non-porous material should be used for all construction; wood is not suitable for walls or floors.

Floors

All floors should be hard-wearing, non-porous material. They should be washable and should slope evenly to the drains. Five cm thick clay tiles bedded in furane or cashew nut cement are best. Granolithic cement is also suitable; ordinary cement

Figure 37
Possible layout for shrimp freezing plant (not to scale).



soon wears, is porous and subject to attack by acids and fish oils. Whatever surface is used in the fish handling areas, it must be such that it can be scrubbed and hosed down. The floor material should be carried up the walls for 15 cm and the joints should be rounded (coved) where this is practicable.

Using trolleys with rubber-tyred wheels prevents the damage which occurs when heavy boxes or tubs are dragged across the floor.

The floors should fall to the drains. A 1 in 90 or 1 in 100 slope is suitable. Slopes of more than 1 in 40 are dangerous. If any ribbing is used, the ribs should run towards the drains, not be parallel with them. All joints must be smooth and close fitting.

Drains

Floor drains should be wide and deep and have an even fall so that water cannot remain in them. They should be covered with removable metal gratings which should be level and flush with the floor. Outlets should have a catch basin outside the process area made of waterproof concrete. Drainage pipes should have a minimum internal diameter of 10 cm. Where a drain goes through a wall, a vermin-proof seal is essential. All drains should be designed so that cleaning with a rod is easy.

Walls

Walls in the process area must be waterproof, smooth surfaced and washable. Ceramic tiles are best but these are expensive. Corrosion-resistant metal such as stainless steel (expensive) or aluminium is also good. Such protection should be carried up the wall above shoulder height. Where concrete is used, it should be painted with high gloss, light coloured, non-toxic paint.

Ceilings

These should be in a continuous, smooth, unbroken surface, painted with white, high gloss, non-toxic paint. Flush light fittings and ventilation fittings are desirable.

Doors

These should be wide and self-closing. They must be smooth surfaced for easy cleaning. Metal plates should be fitted flush with the floor surfaces to prevent rat damage and entry. A metal or washable well-painted light-coloured surface is needed. Wherever fly screening is needed, either a metal mesh screen or air curtain should be fitted.

Windows

Natural light is both better and cheaper than artificial light, so large simple windows should be fitted. Glass is not essential and is a potential hazard to the product. If glass is used it should be in a few large panes, not a large number of small ones. All windows should be at least 1 m above the floor. Window sills, if any, should be of concrete and sloped downwards at an angle of 45 degrees. Window frames should be of aluminium or well painted galvanised steel; where wooden frames must be used, these must be well painted.

If glass windows which open for ventilation are used, fly screens which can be removed for cleaning should be fitted. Fly screen mesh can often be used instead of glass windows.

Ventilation

Air conditioning is not really needed and is expensive to install and operate in commercial premises but good ventilation is essential. Air conditioning is not a substitute for using plenty of ice. Exhaust fans are very useful; these must be fitted so as to exclude insects when not running — a correctly weighted flap is adequate. Ventilation ducts should be flush fitted and all ventilation openings screened with

fly mesh on frames which can be removed for cleaning (except where fans are fitted).

Lighting

Fluorescent lights provide the best alternative to natural daylight. In the general working areas a minimum of 20 foot candles is needed; this is roughly equal to a loading of 2–3 watts per square foot (or 20–30 watts per square metre) using fluorescent tubes. In inspection areas, 50 foot candles are needed. Light must be good wherever knives are used.

Toilet facilities

Rooms should have walls of smooth, washable light coloured surfaces. Floors should be non-porous, washable and easily cleaned. Rooms should be well lit and *must be kept clean at all times.* They must not open directly on to the processing area.

Flush toilets should be provided at the following ratios:

Number of employees	*Number of toilets*
1 to 9	1
10 to 24	2
25 to 49	3
50 to 100	5

One additional toilet for every additional 30 employees.

A handwashing facility is best provided in the factory entrance *so that it is used every time anyone enters.* It should have hot running water and soap; pedal operated taps are best. Single-use towels should be provided; however, no towels are needed for a wet process room. Where paper towels are used, a bin must be provided and the contents burned at intervals well away from the process area.

WATER SUPPLY

This is one of the most critical factors in making products which will be safe to eat and will meet the required microbiological standards. Water from rivers which are also used as lavatories is certain to contaminate the product with faecal bacteria. Dock water is always filthy. Such water is always quite unsuitable for any part of any process or for washing down premises. Even local authority water supplies may need both filtration and chlorination to suitable levels. The water supply should be checked for microbial contamination at frequent intervals. The interval varies with conditions found at earlier examinations and may be from once a week to about once a month.

Both hot and cold water supplies for use on the process lines and in wash basins should be at a minimum pressure of twenty pounds per square inch (1.4 kg/cm^2). Pipes must be big enough to carry the required volume.

A high pressure system should be available for washing down the premises and equipment at a pressure of 400 pounds per square inch (28 kg/cm^2). A portable system such as the 'Maelstrom' is very good.

All water used on the process line or for cleaning down should be chlorinated. This is *not* a substitute for clean working but it will reduce both the number of micro-organisms and prevent or reduce odours. When chlorine or a chlorine salt is added to water, chlorine molecules are released. If the water contains protein particles or bacteria, molecules of chlorine attach to these, so some chlorine is used up i.e. is no longer free to do its work. Some comes off as a gas – you can smell it – chlorine is poisonous and has been used as a war gas so it must not be breathed. Only water containing free chlorine has any value as a bacteriocide and

this is why the level of free chlorine must be checked at frequent intervals using a disc comparator.

An in-line chlorination system is best; this should be of a type in which the level of chlorine can be varied as and when necessary. A maximum of 5 ppm of free chlorine should be present in water which comes into contact with the product. Fifty ppm should be used for cleaning down the premises where a two- or three-stage cleaning process is employed; where a one step cleandown is used, as with the 'Maelstrom', 200 to 400 ppm is used.

Chlorination may be effected by:

(1) Injection of chlorine gas.

(2) Injection of sodium hypochlorite liquid.

(3) Adding calcium hypochlorite as a powder.

Whatever method is used, a disc comparator should be available to check the level of free chlorine. Daily checks are needed with an automatic system, or every two hours if a manual system is used. Where a manual system with a tank is used, the dwell time in the tank should be at least 20 minutes.

EQUIPMENT

All equipment must have smooth, easily cleaned surfaces. Tables should be of metal, preferably stainless steel. Toxic metals, e.g., copper, must not be used. Plastic cutting boards should be used. Plastic, plastic reinforced with glass fibre (GRP), aluminium, and stainless steel are all suitable materials for containers such as fish boxes and tubs; freezer trays should be of metal.

Sinks and other facilities for cleaning equipment should be in a separate room from the process area. Equipment should be washed with detergent in preferably hot water, scrubbed with a plastic-handled nylon bush and then rinsed in water chlorinated to 50 ppm. Containers should be left upside down to dry.

CLOTHING

Protective clothing such as caps, gowns or coats, gloves and boots should be provided. Cloth items should be washed, preferably in boiling water. Plastic and rubber items should be washed inside and out and then soaked in water chlorinated to 50 ppm and then drained. They should be inspected before reissue. The laundry should be outside the main process area, as should the issue room.

Factory hygiene and sanitation

In order to produce a product which is consistently safe and of high quality a producer must have a good understanding of the principles underlying hygiene and sanitation. This is a broad field covering all aspects of food processing and the following notes will highlight those areas of particular importance.

BUILDINGS

First and foremost, we must consider the factory building. It should be sited away from activities which encourage flies, rodents and other vermin. Sites to be avoided are those adjacent to municipal refuse tips. Ideally, the factory should be purpose-built and not a modification of an existing building, since this is seldom satisfactory. The cleaning operation in a food processing plant involves the use of large quantities of water and it is important that all surfaces in the processing area should be of materials which are impervious to water. In addition, the floor should be sloped in such a way that water does not collect in pools but runs quickly into drainage channels set into the floor. The drainage channels should be covered with metal grids which can be removed for cleaning purpose. The ceilings should be as free from exposed pipework and other services as is possible since these only collect dust.

The processing area should be well lit. This will make it easy for staff to carry out their duties and, additionally, will make it far easier to ensure that the area is kept clean, and that it stays that way. Good ventilation is important but care should be taken to ensure that windows are adequately screened and that, where doors cannot be kept closed, an air curtain is used to prevent the ingress of flies. Flies are notoriously dirty and can carry disease and should therefore be excluded from the processing area. Fly-catching devices using ultra-violet light to attract the flies seem to be ineffective in tropical areas; it is thought that this is due to the fact that the sun shining through open windows is, in fact, a brighter source of ultra-violet light than the insect trap itself. For this reason, it is probably more effective to exclude flies rather than try to catch them once they have entered the plant. Domestic animals, such as dogs, cats, chickens, ducks etc., should never be allowed to wander around in the processing area. All of these animals are warm-blooded and can carry organisms which are pathogenic to man in their intestines. Rats, mice and cock-roaches may enter the plant where drainage channels pass through the walls to the outside. The provision of a water trap at this point should prevent the entry of such vermin.

There must be an adequate supply of good quality water both for processing and cleaning. This may be from a piped supply or a well/bore hole but, whatever the source, the same criteria should be applied before it is used for food processing. The water should be free of suspended material and chemical pollutants and above all free from bacteria which indicate faecal pollution of the supply, i.e., *Escherichia coli*. Where the supply is contaminated with such faecal indicator bacteria, then chlorination will effectively get rid of this but, in any case, it is a good practice to chlorinate the supply since this will help to maintain standards of hygiene in the

factory. For this purpose, no more than 5 ppm of free chlorine would be necessary and at these levels there should be no problems of metal corrosion or tainting of the product. For cleaning purposes, much higher chlorine levels are required and this aspect will be dealt with later. Where it is necessary to hold water in storage tanks, great care must be exercised to ensure that the tanks are kept clean and that they are so designed as to prevent the ingress of birds and rodents. Nevertheless, tanks should be regularly inspected and cleaned.

EQUIPMENT

In many parts of the world, it is traditional to carry out many tasks squatting on the floor; this practice has no place in a modern food processing factory since it is impossible to keep the floor clean enough for food processing. For this reason the production area must be provided with tables etc., on which the various operations can take place. These tables should have smooth impervious surfaces (stainless steel is ideal) with no crevices which can harbour food particles on which bacteria will grow. The table tops should be supported on rigid bases, which can be of any impervious material, but once again they must be designed so that they are easy to clean.

Any equipment used for processing must conform to the same basic design concept so that they can be easily cleaned and will not provide sites for bacterial growth. Unfortunately, not all food processing plants are designed with these criteria in mind and care is needed when selecting new equipment. Wood should not be used in places where it will come into contact with foodstuffs. The open grain structure of wood means that it holds moisture and encourages microbial growth which is then transferred to the product. There is *no* known method for ensuring that wooden surfaces are adequately sanitised. Even after washing with a disinfectant solution it is possible to isolate organisms which are protected in the crevices in the wood surfaces. Accordingly, wherever possible, wood should be completely excluded from the processing area and from cold storage facilities.

STAFF

Many problems of hygiene arise from the staff themselves; it is therefore important to ensure that they are healthy, and that they have a basic understanding of the need for good personal hygiene. Staff should not be allowed to work in a food processing area whilst suffering with intestinal infections, since these may be transmitted to the food. Open cuts and boils on the hands may harbour pathogenic staphylococci and any staff with such lesions should have them covered with a waterproof dressing. If this is not possible, then the members of staff affected should be transferred to areas where they do not directly come into contact with the food.

It is essential that the staff are provided with an adequate number of clean lavatories. These should ideally be sited well away from the processing area and better still in a separate building. Staff must be encouraged to wash their hands after every visit to the lavatory but it is often easier to enforce this rule if wash hand-basins are situated at all the entrances to the processing area. Using this system everyone who enters the food processing area is compelled to wash their hands even if they have not come directly from the lavatories. Due to the fact that in a seafood processing plant most of the operations are wet operations there is no need to provide towels of any kind at the wash hand-basins in the processing area. This avoids all of the problems associated with communal towels. Staff should be encouraged to keep finger nails short and clean, since these can be a source of contamination to the product.

Staff should not be allowed to wear outdoor clothing within the processing area, since standards of hygiene outside the factory will invariably be lower. This will mean that cloakrooms will need to be provided where outdoor clothing can be

stored during the working day and where staff can change into clean overalls. It should be a function of the factory to provide all workers with clean overalls, hats and where appropriate rubber gloves. It is an unfortunate fact that a considerable proportion of staff will be carriers of *Staphylococcus aureus* and the organism will be found on their hands and in the nose and throat. It is impossible to rid the skin of these organisms by washing, which means that, where there is a great deal of handling of the product, rubber gloves are advisable. Where gloves are provided every effort should be made to ensure that they stay clean; a satisfactory method for cleaning rubber gloves is to wash them inside and out and then soak in a solution of sodium hypochlorite containing 50 ppm of free chlorine. The wearing of hats in the food processing areas is to ensure that there is no fall-out of hair, dead skin scales, or, in some cases, dirt from the hair on to the food. It follows that any hat, to be effective, must cover all of the hair. Handkerchiefs are a source of contamination and because staphylococci may be resident in the nose they may harbour this organism. Staff should be encouraged to use paper tissues where possible and these can be burned after use.

SANITISATION

At the end of the day's work, the production area will be littered with particles of food, water and general dust and dirt. If the quality of the product is not to fall it is essential that the whole area is adequately cleaned and disinfected. Cleaning is essentially a three-stage process:

(1) All large debris must be removed with a brush or scraper, whichever is most appropriate.

(2) The whole area must be washed with clean water and tables and utensils scrubbed clean with a plastic scrubbing brush. It may be necessary to use a detergent to attack dried-on deposits; if so, use a compound especially formulated for the purpose. Many household detergents contain perfumes and these may taint the product if used in the factory.

(3) Disinfect the whole area by drenching or fogging with bleach (50 ppm free chlorine). Do not rinse the bleach away but leave it to act and wash down with fresh water at the beginning of production the following day. Difficult cleaning jobs may warrant the purchase of a high pressure cleaning machine. These machines deliver a jet of water at approximately 500 psi and most have facilities for mixing detergent or disinfectant with the stream of water. These machines are particularly good for cleaning items of equipment which, due to their intricate design, are difficult to clean with a brush. They are also very good for cleaning rubber conveyor belts such as those found on automatic prawn grading machines. Due to the very high pressures generated by these machines, care must be exercised in their use since they may inflict considerable damage to badly maintained cement floors and walls; they may also cause injury if directed at other personnel. It is usually found that, although these machines are good at removing deposits on machinery, walls, floors and drains, they do not carry away the loosened dirt because of the low volumes of water involved. It is therefore necessary to hose down items which have been cleaned by machine with a low pressure hose and large volumes of water.

MAINTENANCE

It is often found that factories which, at their inception, were well designed and constructed deteriorate rapidly due to lack of maintenance. It is impossible to maintain good standards of hygiene in a factory with cracked floors, damaged walls and generally broken down equipment. Every effort should be made to maintain the factory in as nearly new a condition as is feasible.

Modern packaging methods

In this session we will be concerned principally with the latest developments in the field of fish packaging.

As you realise, packaging in various forms has been used for thousands of years for carrying foods. Wooden boxes, leather and cloth bags, earthernware pots and even string or rope for making bundles are typical examples. The prime objective is to keep food materials together for ease of transport. Early forms of packaging for fish products consisted mainly of wood made into crates, woven bamboo/palm for baskets, and barrels for pickling. Nowadays, metal, glass, paper and particularly plastics have become more important, especially as the retail packaging unit has developed to cater for expanding and improved marketing operations.

DEVELOPMENT OF MODERN PACKAGING MATERIALS

Modern packs and their continued development have arisen in more recent years due to an increasing requirement from both retailers and producers for improvements to, and increased efficiencies of, marketing, storage and handling of fish and related products. Combined with this, a higher turnover of fish products and commercial competition in the market have stimulated developments.

As the fishing industry develops, so does the marketing infrastructure and related technology. Marketing in a modern developed nation is a highly competitive field and it is this competition which has spurred industry on into the research and development of new forms of packaging which may give one manufacturer and retailer an advantage over another. This is especially so in the USA where retail consumer packs are probably the most advanced in the world.

We are concerned, therefore, with two main areas of packaging:

(a) Containers used for storage and handling on the fishing boats and fish markets at the port.

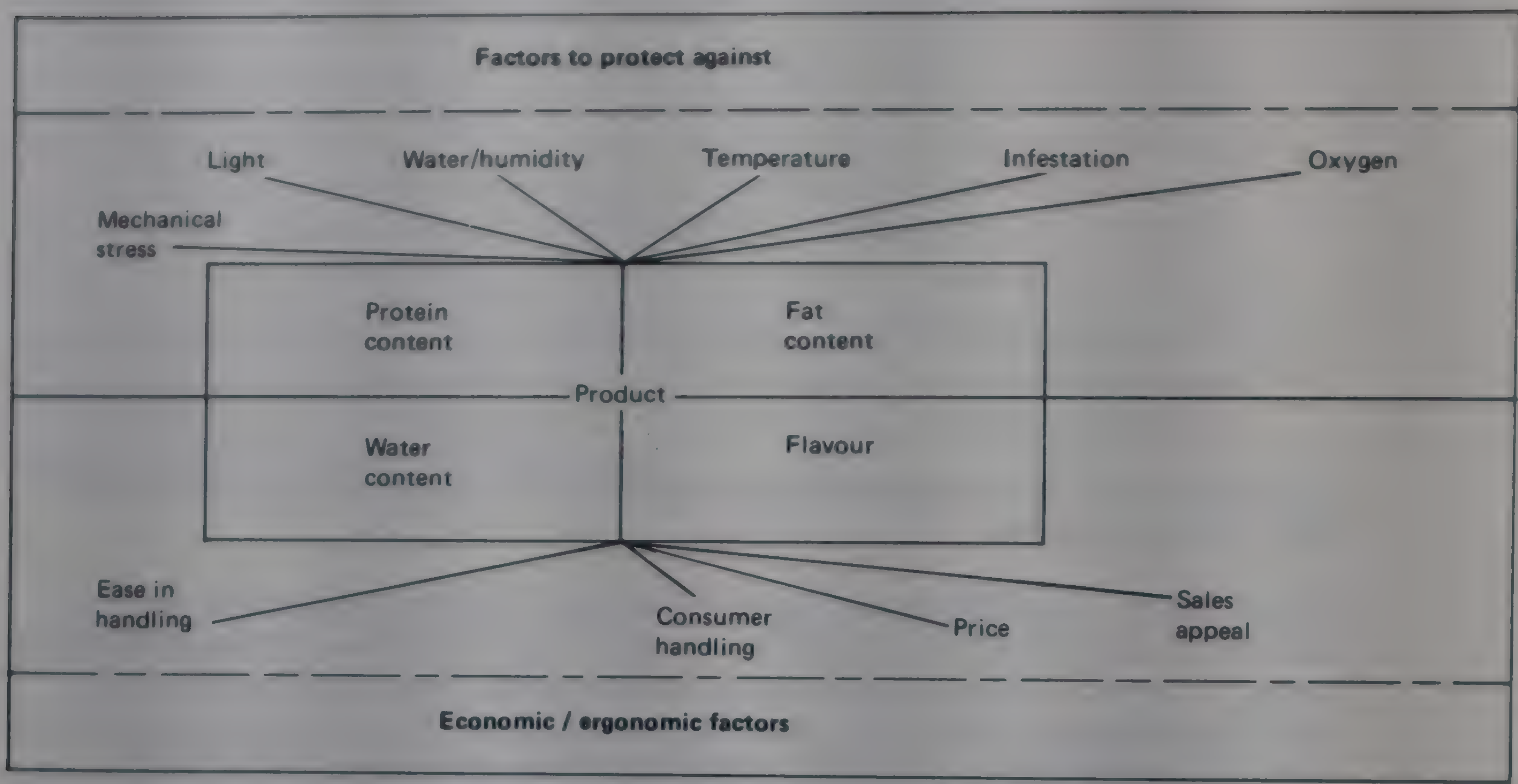
(b) Packs used mainly for sophisticated retailing.

It is in this latter section that most of the sophisticated developments have occurred, although as we will see the use of, for example, plastics for boxing fish at sea has become commonplace.

FACTORS WHICH AFFECT CHOICE OF PACKAGING MATERIALS

Figure 38 shows the various factors which influence the choice of packaging materials:

Figure 38
Factors which influence the choice of packaging materials.



Source: 'Principles of Food Packaging, an international guide'. Edited by R. Heiss, Munich. Published by arrangement with the Food and Agriculture Organization of the United Nations © FAO (1970), by P. Keppler Verlag KG, Abt. Central-Druck, 6056 Heusenstamme, Industrie-strasse 2, Federal Republic of Germany.

As packaging technology develops it is, in effect, attempting to optimise these requirements, tending towards the ideal, and yet economically viable, package which is suited to the particular product in question. The main requirements in the case of fish are as follows:

1. Reduction of fat oxidation, especially in the more fatty species such as mackerel, herring and salmon.
2. Reduction of dehydration which leads to severe textural deterioration and freezer burn.
3. Reduction of bacterial and chemical spoilage.
4. Elimination of drip – unsightly liquid which can collect when fish is being stored dry.
5. Prevention of odour permeation.

Other desirable characteristics which must be considered are:

- wet strength in the case of wrapped wet fish
- non-stick properties, especially in frozen portions
- pliability under frozen conditions where fracture may easily occur
- resistance to sub-zero temperatures for frozen product
- oil resistance
- strength and full retortability for aseptic produce.

TYPES OF MODERN PACKAGE FOR FISHERY PRODUCTS

Iced fish – bulk shipment

After the fish have been caught, they may be loaded into wooden boxes and iced. These hold from 14 to 56 kg of fish. Similar units are also used throughout the distribution networks. Nowadays, this system is to some extent being replaced by non-returnable matchwood boxes, light alloy boxes, and plastic crates. A present-

day estimate is that about 70 per cent of boxes used by trawlermen are of wood construction, 25 per cent are made from plastics, and the remainder from light alloy.

Paper pulp boxes impregnated with resins have been tried but more successful are the fibreboard box and corrugated board cartons. These are waxed or coated with polyethylene and sometimes with expanded polystyrene linings to improve the insulation. They are normally used for the storage and transport of wet fish from port to fishmonger, caterer or institution. The boxes are delivered pre-printed and flat, and are folded and stitched *in situ* using rust-proof staples. After filling with fish and ice, the box is sealed with heat-sealed polypropylene or metal tape for security. Such boxes are of course non-returnable and vary in size from approximately 3 to 28 kg. Other uses for these are:

- freezing wet fish
- storage of wrapped and unwrapped frozen fish
- IQF and cured product storage

Another recent development in the plastics field is corrugated polypropylene. This has not been used to a great extent in the fishing industry but will certainly find useful application in future.

As we shall see, there are other applications for polyethylene-coated fibreboard. For wet fish, however, the requirements of size, wet strength, protection and handling capability are met by this material very well.

Iced fish — retail packaging

Traditionally, wet fish are sold on a counter surrounded by ice. The modern trend, however, is towards a standardised unit pack which, for wet fish, is normally a tray containing the fish, coated in a thin transparent film overwrap. The tray may be of formed paper pulp, which has the advantage of absorbing the excess moisture or drip, but the disadvantage of collapsing when too wet. The problem of drip can, however, be counteracted by dipping the fish into a solution of polyphosphates. These in effect bind the water and prevent its subsequent loss during storage.

Normally, the tray is formed from foam polystyrene, the film wrap being usually cellophane laminated with polyvinylidenedichloride (PVDC), polystyrene, oriented polypropylene (PP) or polyvinylchloride (PVC). These films have excellent water vapour barrier properties and prevent excessive water loss from the fish flesh.

Sometimes a vacuum pack is used and in this case higher barrier films are required such as PVDC or polyester (PE). Strict hygiene procedures must be observed during the preparation of vacuum packed fish. This is because, under anaerobic conditions such as those found in vacuum packed foods, the development of anaerobic pathogens can easily occur. This can lead to severe food poisoning.

The tray and over-wrap pack is common in fast-turnover supermarkets in the UK. However, prolonged storage of wet fish under chilled conditions is best carried out on ice.

Pre-packed fish have the following advantages;

- Self service by the customer is facilitated and this is conducive to rapid sales turnover.
- Scrutiny by the customer is allowed.
- The risk of contamination by air-borne dirt and bacteria is reduced.
- Brand name merchandising and date stamping etc. is facilitated.

Frozen fish packs

Freezing is now the most important method of preserving fish for long periods and has obvious advantages in the retail market situation. In fact, it is seldom realised how important the packaging is in frozen produce, the most important feature

being the water vapour barrier properties of the material. Dehydration of frozen fish results in undesirable freezer burn and increased oxidation of the product. The pack must, therefore, meet all our requirements for a good package as outlined in Figure 38.

The most common pack for frozen fish is the inter-locking, printed, waxed carton with a heat-sealed inner pouch of polyethylene, cellulose or nylon. The carton is produced by punching out pre-formed shapes from large sheets of this material, which are normally pre-printed, and folding these into carton blanks ready for filling. Sometimes the inner pouches can be placed straight into the cooking pan mainly when used for whole fish fillets, and these are referred to as boil-in-the-bag pouches. Obviously, the mechanical strength demand on these is very high considering the extremes of temperature to which they are subjected.

Recently, with the reduced yields of white fish catches, the fishing industry has been moving towards frozen blocks of filleted fish which are processed into fingers or pieces. In fact, up to 60 per cent of fish consumed today in the UK is as fish fingers or pre-formed fish pieces.

These are packed into folding cartons made from polyethylene coated paperboard. Polyethylene prevents water loss and also heat-seals the carton. The shape is ideal, the finger shaped product fitting very neatly and efficiently into the package. Polyethylene has better water carrier properties than wax and, therefore, in this case an inner lining is unnecessary and this of course results in a considerable cost saving. In addition to this, the product is usually breaded and deep fried. This process in effect helps to prevent water loss and oxidation of the product. Packs of this sort are folded, filled and sealed automatically, with very high mechanical efficiency. They usually have simple tear-off ends for ease of use.

This kind of pack offers the marketing person an ideal method of merchandising and, with the present growth of the frozen fish retail markets, it is not surprising that so much technology is involved in this area. Much of today's packaging technology is tied up with improving the laminates used in combination with paperboard, and the method of direct printing.

Nowadays a lot of fish are sold in the form of a bulk retail pack for the home freezer application. Material used in this case is normally a polyethylene coated paper sack or bag which, as the contents are used, can be rolled down and reclosed by hand. Such packs are normally filled with fish fingers or pieces of standard size and weight. Where the product is of varying size and weight, many high speed filling lines utilise an automatic, computerised, check weighing machine which selects and groups products of the correct weight for packing. This ensures that no underweight or overweight packs are made, thereby improving the line efficiency — an all-important factor in high turnover operations. Nowadays a lot of fish are exported in the frozen state. In this case corrugated fibreboard boxes are often used in combination with a polythene bag liner. These can be either filled with glazed fish and IQF products or with cellophane wrapped and cartoned products ready for retail. Boxes of this sort are invariably sealed with metal or polypropylene strapping which provides both a carrying mechanism and security.

Aseptic packs — cans

Salmon, tuna, sardines and pilchards form the main fish products currently canned. This is mainly because of their high oil content which is usually a problem due to the risk of rancidity.

Canning has been practised for many decades and recent developments primarily involve new container shapes, easy-to-open lids, and aluminium bodies. Although the traditionally cylindrical can is by far the commonest type, the sardine can has been developed and aluminium varieties are available with scored top panels for easy opening. These are used, not only for sardines, but also for fillets of larger fish and small herrings in oil or sauce. They are laquered internally, as is tin plate, with

phenolic (or 'sea-food') laquer which is especially resistant to sulphurous attack from the high proportion of sulphur amino acids contained in fish and meat products. Trimethylamine oxide (TMAO) in the product is a depolariser which can lead to pinholing unless laquer is applied. The main advantage of aluminium over tin plate is the fact that easily opened ends can be used. However, tins of this kind can be up to twice as expensive.

Aseptic packs — pouches

These are a fairly recent development and have become practicable recently because of the improved types of polymer and lamination methods available. Flexible pouches serve essentially the same function as cans, i.e., they maintain absolute product sterility after undergoing controlled heat sterilisation in a retort.

A typical specification would be: 0.012 mm polyester or polyamide as external ply; then 0.009 foil with 0.065 mm of polypropylene or modified high-density polyethylene film as the heat-sealing ply inside the pouch.

Pouch-forming material is obtained in the form of a roll which, in a continuous operation, is cut to the correct length, heat-sealed and chopped to form the pouch which is then filled, evacuated and heat-sealed prior to retorting in a process similar to canning.

The advantages of pouches can be listed as follows:

1. They have reduced weight and volume, especially when empty.
2. They are available in a good range of sizes.
3. They can be easily opened using tear-off corner strip.
4. They can be used for boil-in-the-bag applications.
5. They involve less process time due to their large exposed surface area; therefore, a better quality of product results.
6. They have marketing appeal.

However the disadvantages are:

1. They are less robust than cans, and are therefore associated with an increased risk of infection.
2. They have no real cost advantage over tin plate because of the necessity to pack the pouch within an outer cardboard carton.

Potential for developing nations: Generally speaking the normal can does not present the problems associated with the filling of flexible pouches and with their subsequent abuse. For a country with a limited technological background, a can would be preferable. However, tin plate can be very expensive when it is necessary to import it from overseas, especially in a pre-formed condition. Reels of pouches, however, to take the same volume capacity of product as cans, would be much lighter and take up less import space. Additionally, machines to form and fill cans are vastly more expensive than the machines used to carry out the same operation for pouches. In fact, machines used for forming and filling cans must usually be centralised. Pouches, however, can be formed at a number of sites and distributed locally for simple filling, sealing on a simple bar sealer, and autoclaving.

Such developments could improve living standards by making processed fish available to people who would otherwise not have the opportunity to eat this product. However, at this stage of development the pouch, after sterilisation, requires careful handling to reduce the surface contamination which could result in pathogens entering the pouch in the event of pinholing. Various codes of practice have been developed to cover the handling and storage of pouches. It is doubtful, however that these could be strictly adhered to in a developing country.

Flexible laminated pouches have also been used for frozen kippers and similar products without sterilising them. This results in a high quality, long shelf life product with no detectable rancidity. As mentioned above, the need for strict hygiene in the production of this type of fish product is essential where there is a risk of the growth of pathogenic organisms.

Aseptic packs- semi-rigid containers

Two very recent developments are the 'plastic can' and the extended foil laminate cup. The former was developed in Sweden in 1977 and is still undergoing extensive trials. The can is rectangular in shape and is constructed of a polypropylene/foil laminate which can be printed. The latter is produced by stamping out shallow cup shapes from a reel of aluminium foil laminated to oriented plastic film slightly thicker than that used for the flexible pouch. The cup is then filled and a flexible lid of similar material is heat-sealed in place.

Developments in this area offer considerable potential as a replacement for conventional tin plate cans which are becoming very expensive.

Smoked, salted and marinated fish

These methods of preservation result in improved storage life under chilled conditions but it is important to realise that they are still extremely perishable products, vulnerable to oxidation, dehydration and bacterial infection. The packaging used must be impermeable to water vapour, oxygen and flavour volatiles. Glass bottles are commonly used for cured fish and vacuum packaging can be used as long as proper controls are maintained during storage. Anaerobic conditions can lead to the growth of *Clostridium botulinum,* which can form the toxin causing botulism. Strict hygiene and storage control practice (especially during retailing) is required with this type of product where the acidity is not necessarily high enough to stop the growth of pathogens. Many fatal cases of botulism have been reported caused by failure to adhere to the correct procedures.

Where fish such as herring are marinated in vinegar which is mainly acetic acid the acidity may be high enough (or the pH low enough) to prevent the growth of any pathogenic organisms.

Recent developments in cured fish packaging includes the use of polyamide/polyethylene and polyester/polyethylene laminated films. These allow the product to be boiled in the bag. Vacuum sealing ensures that they do not float in the pan during cooking.

The bulk pickling of fish such as herring is now often carried out in polyethylene drums, the traditionally wooden barrels having been replaced.

Shellfish

Shrimp

Shrimp are usually placed in waxed cartons and frozen. These cartons may have an inner lining to prevent dehydration, or alternatively may have holes, in which case they can be dipped whole into water, or opened and sprayed, to glaze the shrimps.

Experiments show that unglazed shrimp can be stored successfully for 12 months in a waxed carton with a moisture-proof overwrap. This means that savings can be made by not having to carry the extra weight of glazing ice which could amount to up to 15 per cent.

The development of individual quick frozen products, made by drum or fluidised-bed freezing, has resulted in the use of polyethylene bags or, more recently, thermoformed linear polyethylene containers with heat sealable and snap-on lids.

Crabs

Crabs are normally sold fresh or alive. However, because of the seasonal nature of crab fisheries, there is a need to preserve some of the catch. Crab meat tends to be very delicate and does not store well even if frozen. Toughening of texture and colouring are problems. Cooked legs that are frozen, glazed, and packed in fibreboard cartons and stored at 0° F (−18° C) remain palatable for around 9 months.

Lobsters

These are invariably sold alive. However, spiny lobster tails from Africa are frozen and wrapped in nitrocellulose-coated cellophane and packed in waxed board cartons. Both crabs and lobsters are also canned in the normal way.

Again, polyethylene coated fibreboard boxes are used for live transport of lobsters. These are placed in the boxes separated with straw, and the box is then strapped for security.

Oysters and clams

These are both very perishable commodities and are harvested only in the cold part of the year in the USA. At present the majority are sold in thermoformed plastic (polystyrene/polyethylene) containers with snap-on lids in the refrigerated form. There is a move towards more frozen products, and polyethylene or nylon bags could be used with an over-wrapped carton. This would provide a barrier against the water loss and oxidation.

Packs used for other products

Roe can be sold fresh, frozen or canned. Fresh roe is packed in sealed polyethylene film bags and refrigerated. Frozen roe may be vacuum packed in polythene-coated polyester film prior to freezing.

Fish pastes and spreads are often available in collapsible metal tubes, which must be kept refrigerated after opening.

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